

CONTENTS

					Page
1. Introduction ..	..	..	..	..	1
2. Chemical Section	..	..	..	..	1
3. Physics Section	..	..	..	..	11
4. Mathematical Section	..	..	..	..	27
5. Statistical Section	..	..	..	..	95
6. Hydraulics Section	131
7. Land Reclamation Section	183
8. General Section	223

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INTRODUCTION.

The Chemical Section has continued to devote attention to soil mechanics with particular reference to canal bank and earth road construction. The apparatus of Proctor for determining the moisture—compaction relationship has been improved and has given results that are likely to be reliable in practice. A large number of earth roads have been examined during the year and it appears to have been established that below about 20 per cent clay, the tendency of the road is to be bad while above this clay percentage, the road is generally good. It should be realised, however, that a good road in dry weather is generally a bad road in wet weather, so that the above conclusion only applies to dry weather conditions.

The Physics Section has been continuing its investigations on the detection of cavities under weirs. The wireless method was abandoned on the outbreak of war and the use of a vibrometer tried. This has now been shown to be unsuccessful owing to the great thickness of the floor and the difficulty of imparting vibrations to it. A method now under investigation is based on the electrical conductivity of soil saturated with water compared with the conductivity of water alone. The apparatus is now under trial at Balloki Weir.

The negative pressures developed in soils have also been under examination. It has been shown that the simple capillary tube hypothesis cannot be applied to soils. The investigation may have an important bearing on the interpretation of well readings especially those taken during the hot months of the year.

The properties of the Field Moisture Capacity Zone in a soil have been studied. It has been shown that if this zone is present in a soil, as it usually is under irrigated conditions, then it is impossible for evaporation at the soil surface to produce a true lowering effect on the level of the water-table. It may, under certain conditions, produce an apparent effect due to the development of negative pressures in the surface layers of the soil. Another important conclusion to be drawn from these results is that salt in the water-table cannot contribute to *thur* formation so long as the zone of field moisture capacity is present.

The silt survey of the Lower Chenab Canal has again been carried out and the results analysed. These may be summarised as follows :—

Upper Gugera Branch.—The bed of this canal is now mostly in scour and there are very few signs of silt movement.

Lower Gugera Branch.—The actual slopes are steeper than those required and silt movement is taking place.

Burala Branch—The slopes are steeper than those required indicating silt movement on the bed. It appears that a large quantity of silt has entered the branch.

Main Line.—The bed has scoured to R. D. 40,000, is stable between R. D. 40,000 and R. D. 75,000 and below this the slope is steeper than that required on the remainder of the Main Line. Silt movement is taking place below R. D. 75,000.

Jhang Branch.—Very little silting is taking place.

Rakh Branch.—The calculated and actual slopes agree. There is very little silt movement. The quantity of coarse silt entering the Branch is small.

Mian Ali Branch—The slopes are steeper than calculated. Silt movement is taking place and there may be some silting.

An attempt has been made to collect data from the silt observation sites on various canal system for the investigation of Lacey's "Shock" Theory. The sites have been divided into four groups with differing characteristics with reference to shock. The data have been examined but so far the results do not support Lacey's shock theory in its present form.

Attempts have been made to improve the methods of sampling both bed and suspended silt. A series of samplers was examined for consistency in results. An important point discovered is that the streamlining of a sampler is not essential to the accurate sampling of suspended silt. A bed silt sampler has been tested which under certain conditions measures the quantity of silt rolling on the bed.

A large number of problems have been referred to the Statistical Section during the year. It is difficult to summarise these further than done in the Report. To indicate the wide range of subjects dealt with, the following important investigations are mentioned—

- (a) Analysis of the Pressure Pipe Observations at Islam Weir ;
- (b) The stability of Bays 5 and 6 of Khanki Weir ;
- (c) Distribution of silt in flowing water ,
- (d) Shock and Coherence in Regime Flow ;
- (e) Silt and Scour in the Main Line, Lower Jhelum Canal , and
- (f) Seepage losses for the Kot Nikka Distributary

The Hydraulic Section has been fully employed throughout the year. The re-modelling of the Western Jumna Canal, the construction of Kalabagh weir and the training works required on the Sutlej River have necessitated a "blitz" on the work. The report of this Section is copiously illustrated with photographs. Photographs are being employed more and more, as it is possible by these to illustrate intermediate stages difficult to extract from final surveys.

The Land Reclamation Section has had a successful year having been expanded into a Land Reclamation Department. The reclamation in the Sukheki area has been so successful that Government has sanctioned two further centres for 1941-42, and is contemplating increasing still further the reclamation operations during 1942-43. It is a pleasure to record the willing co-operation received from the Superintending Engineers in this work. Without their advice and assistance the scheme could not have progressed in the successful manner which the report indicates.

An important investigation on the use of irrigation water has been concluded during the year. It has been shown that the irrigation of cotton, wheat and Senji as at present carried out by the zamindars must lead to the formation of *thur* if salt is present in the soil crust. Two crops—rice and berseem—control this upward movement of salt. As the available water in the rabi is not sufficient for the widespread growth of berseem, rice is the only crop by which *thur* formation can be controlled. The implications of this are dealt with in detail in the report.

CHEMICAL SECTION

Soil grading as an index of stability and the Development of an apparatus for measuring the Optimum Moisture and the Soil Density at Maximum Compaction.

A well graded soil is one in which the proportion of the different fractions are such that the resulting mixture has the maximum density at standard compaction

In order to find out if a soil sample has a size distribution of particles which conforms to a well-graded mixture, two methods can be adopted —

- 1 Analyse the soil mechanically and compare its summation curve with the optimum gradation curve of Hogentogler.

- 2 Determine some other property of the soil, such as density at optimum moisture, and compare it with the value for the same property in a well-graded soil

The optimum gradation is expressed by diagrams in which the percentage of particles smaller than a given size is plotted against the particle size on semilogarithmic scale. This really comes to plotting the summation percentage against the logarithm of the size. One of these curves is shown in Figure 1. It represents an excellently graded soil mortar.

Another curve, which is an extension of that shown in Figure 1, is given in Figure 2 (The curve is shown here in broken line). Certain limits have been assigned to the percentage of particles smaller than a given size and the range of variation is indicated by the shaded band. The lowest size plotted in Figure 2 is 0.005 millimeters, one-tenth of that in Figure 1 though the highest, 2 000 millimeters, is the same in both the cases.

It has been mentioned in previous reports that the mechanical analysis summation curve of a soil can be represented by two single values namely the weighted mean diameter of particles (m) and standard deviation (σ)

Weighted mean size, M —The summation curve of a soil sample gives the percentage of particles below any given size. By taking the readings for two given sizes and subtracting, we can ascertain the percentage of particles whose diameters lie between the two sizes and which may very nearly be assumed as having a diameter lying midway between those two sizes. If this last value is multiplied by the corresponding percentage, and the sum of all such products is divided by the sum of percentages (usually 100), we get a value for the mean diameter of all the particles contained in the sample. This is the weighted mean size, or M , and furnishes a useful measure of the degree of coarseness of the sample.

Standard deviation.—(σ) Not every sample consists of particles distributed in exactly the same way, and it is quite possible that two samples with the same mean size may differ, one having a preponderance of particles with diameters near the mean size, and the other with diameters varying much more widely. Hence it is necessary to know how the various sizes are distributed about the mean size, and consequently the standard deviation is calculated as a measure of their dispersion. To obtain this, the deviation of each size from the weighted mean size is squared and multiplied by the corresponding percentage and then the sum of such products is divided by the sum of the percentages. The square-root of the quotient gives σ and the smaller it is the more uniform can the sample be assumed to be.

If we determine (m) and (σ) for the optimum gradation curve we find that this numerical value is very nearly the same or the ratio m/σ is very nearly equal to unity. Another property of the optimum gradation curve is that if it is plotted on a semi-logarithmic scale the sub-tangent is very nearly equal a unity. If the horizontal scale is marked in diameters, then this really means that the value at T will be nearly one-tenth of the value at N. This is shown in Figure 3. (See parts T, N, T₂, N₂.....).

A good soil mortar must contain clay and fine, medium and coarse silts as well as coarse sand. It is not always possible to find various grades of silts and sand to make up a well graded mixture with the soil available. If the optimum gradation curve is kept as the standard then the maximum quantity of the available coarse material to be added can be determined by plotting the soil-sand mixtures as summation curves on semi-logarithmic scale. With increasing amounts of sand added to the soil the summation curve, shifts towards the optimum gradation curve, until with a certain percentage it is as near the optimum curve as it is possible for it to be. This will be clear from Figure 4.

Compaction Test Apparatus.

The compaction test seemed to offer possibilities of classifying soils on the basis of the maximum density attainable under a specified set of conditions, since the entire basis of soil grading is the maximum density. The well-known Proctor tests for compaction and stability, though useful in the field for purposes of control, are not sufficiently accurate for laboratory purposes because of the possibility of prohibitive personal error (See Engineering Properties of Soils by Hogentogler, page 253.)

A modified compaction test which seemed to give more reproducible results was devised. This apparatus can be used in the field with the same facility as in the laboratory.

The soil compaction test apparatus (Plate 1) consists of a brass cylinder 7" long and 2.5" internal diameter. It is fixed in an iron framework in such a way that a sliding weight of 3 kilograms which

can be used as a rammer, can be adjusted to fall freely from any desired height. Compaction of the test sample is carried out by means of a piston which can just move freely in the cylinder on which the rammer can be made to fall from a pre-determined height. The piston is attached to an iron disc of about 1.25" diameter for receiving the blows of the rammer. The piston and the disc are connected by an iron rod. Reading is taken by a special device which is shown in Plate I along with the compaction apparatus. It consists essentially of an iron rod, fixed close to the brass cylinder, carrying a moveable pointer which can be adjusted at any point by the help of a screw. One end of the pointer touches the lower surface of the iron disc which receives the strokes from the falling rammer. As the soil is compacted the pointer indicates the volume of the soil in terms of the readings on the scale, fixed to the framework of the apparatus. The scale readings are calibrated to start with, by taking known volumes of soil in the cylinder. Two hundred gms. of soil passing the 1mm. mesh sieve are used for each test. The requisite amount of water is added to the soil and thoroughly mixed by hand and transferred to the cylinder. The piston is placed in position and nine strokes are given with the rammer falling from a height of 2.0 feet. During this compaction the end of the pointer is not kept under the disc of the piston. The piston is then taken out and any soil sticking to the sides removed. The pointer is now placed with its shorter arm under the disc and the final stroke is given. The reading is taken while the rammer is resting on the disc. From the volume of the soil the density is calculated and expressed in lbs. per cubic feet. A density of 1.0 corresponds to 62.34 lbs. per cubic feet. At the end of each reading the soil is tipped out and mixed with more water and the compaction test repeated. A series of readings for density are obtained corresponding to the various moisture contents. These values when plotted give two straight lines one for increasing density and one for decreasing density. The point of intersection of the two lines corresponds to the optimum moisture and maximum density attainable. In order to fix the working conditions of the apparatus certain preliminary experiments were carried out. These were to determine:—

- (1) The number of strokes required to bring the soil to maximum consolidation.
- (2) The height from which the rammer should be allowed to fall.
- (3) The effect of soil moisture on (1) and (2).

The results are summarized in Table 1 and Table 2. Table 1 gives the relation between the height from which the rammer is allowed to fall, the number of strokes and the volume of the soil at optimum moisture (=12 per cent). Table 2 gives the relation between the number of strokes from 2.0 feet height and the volume at various moisture contents. As a result of these experiments ten strokes from a height of 2.0 feet was fixed as standard. Typical density moisture content curves for a number of soils are given in Figure 5.

The compaction apparatus is portable and tests can be carried out in the field. It has been found useful for the determination of the amount of coarse grade required for soil stabilization. Increasing amounts of the coarse grade are added and the density moisture content curves determined. The mixture giving the highest density gives the most suitable proportion. Similarly the amount of clay binder required for sand stabilization can be determined with the help of this apparatus. Typical curves in this connection are given in Figures 6 and 7.

The effect of the coarseness of sand on the amount required to stabilize a given soil (clay 12.5 per cent) is brought out well in these figures. It will be seen that 20 per cent of sand having a mean diameter of 0.199 mm is required to bring the soil to maximum density while 40 per cent is required to produce the maximum density with a sand of 0.537 mm mean diameter.

Relation between Mechanical Properties of Soil and Road Performance.

A knowledge of the properties which are important in deciding the suitability of a particular soil for road making is of prime importance. The optimum soil mortar requires approximately the following ingredients —

Name of fraction	Limiting Diameter of particles mm	Percentage
Clay	0.002	5
Fine silt ..	0.075	20
Medium silt ..	0.20	15
Coarse silt ..	0.6	25
and ..	2.0	35

The above mixture gives the maximum density and is said to be well graded. The mechanical composition can be expressed in the form of a "summation curve" in which particle diameters are plotted as abscissae on a logarithmic scale, with the corresponding total percentages as ordinates on an arithmetical scale. The ideal mixture according to Hogentogler is shown in Figure 8 along with the summation curves of typical Punjab soils. These soils were collected from earth roads and the condition of each road at the time of sampling is indicated on the corresponding curve. An examination of these curves show that soils conforming to the Hogentogler curve are badly cut up under traffic, under the climatic conditions of the Punjab. On the other hand, soils farthest removed from Hogentogler's curve are the best as regards road performance. A careful examination of individual fractions, however, at once shows the importance of the percentage of clay in these soils. It appears that, the higher the percentage of clay the better the road under Punjab conditions. This is clear from

Figure 9 in which the clay contents of soils collected from several earth roads and berms of metalled roads are plotted. The following conclusions may be drawn from the results —

- (1) When the clay percentage is below 10 the road is always bad
- (2) When the clay percentage is between 10 and 20 the road may be good, or bad and may be described as medium.
- (3) When the clay percentage is above 20 the road is always good

It must be remembered that, in the Punjab, dry conditions predominate and, therefore, the conclusions are only valid for the peculiar climatic conditions prevailing in this Province. It is obvious that a soil with a high clay content which may present a hard surface when dry will be easily cut up when wet. However wet days being few, the general condition of the road conforms to the clay content. In order to convert a dry-weather good road into an all-weather good road the surface should be treated so as to prevent the ingress of water from the top. There is no likelihood of any trouble due to capillary moisture provided the soil is free from salts and the water table is below the capillary zone. Similar remarks apply to hygroscopic moisture which does not cause appreciable volume changes in the absence of harmful salts. This has been discussed in previous reports.

A reference to Figure 8 shows that most of the good soils have a maximum particle size of the order of 0.1 mm. and therefore they might fairly be taken as mixtures of clay and fine silt. Coarser particles are either absent or rarely more than 5 to 10 per cent. Thus these soils would form only 25 to 30 per cent of a well graded mixture.

Movement of Moisture in Soils.

The laws governing the transmission of pressure through water-saturated soils are well known. The saturation deficit that would just prevent the pressure transmission is a point of considerable interest. When water is applied to a soil surface, the whole of it will be added to the sub-soil water-table if the soil is saturated. When the soil is unsaturated a portion of the water may raise the moisture content of the soil and the level of the water-table may not be affected. From laboratory experiments conducted in glass tubes filled with sand, it appears that pressure transmission and additions to the water-table may take place when a soil is saturated to the extent of 90 per cent of the pore space.

It is well known that the rate of percolation of water through soils depends to a large extent on the method of packing. Since there has been no standard method of packing, the permeability of soils to water has never been given the same significance as the transmission constant of sand for instance. The difficulty of packing has been overcome by the help of a compaction machine described in this report.

The soil is compacted in this apparatus at the optimum moisture. After the standard compaction the ring containing the soil is removed and clamped in the percolating cylinder with sand below and above the soil. A fairly coarse sand is used as its object is to support the soil. Since the permeability of the soil is small compared to that of the sand, the presence of the sand introduces no error. A constant pressure head of 10 feet of water was used for measuring permeability. One hundred and fifty grammes of soil just fill a cylindrical ring 2.5" in diameter and 1" long. It is better to use approximately this amount of soil as it is difficult to remove excess of soil and maintain a smooth surface.

For each soil, a particular moisture content is necessary to secure maximum density during compaction. The rate of percolation of water through a soil compacted at different moisture contents has been measured. The results given in the following table show that there are large variations in the rate of percolation according to the amount of moisture present during compaction.

TABLE 3.

Rate of percolation through a soil block 1 inch thick and 2.5 inch diameter under varying heads of water.

Head of water in feet.	MOISTURE AT WHICH COMPACTION WAS MADE AND THE RATE OF PERCOLATION IN C C PER HOUR		
	5 per cent moisture	10 per cent moisture	15 per cent moisture
2	0	0	0
4	6.0	1.1	0.2
6	9.0	1.1	1.0
8	17.0	1.1	0.8
10	21.5	1.5	1.0

The optimum moisture content to secure maximum density in the soil was found to be 10 per cent. Percolation through the soil at maximum density is considerably less than that through the soil compacted with a moisture content below the optimum. It is also seen that any increase of moisture above the optimum does not materially affect the rate of percolation. These results are very important from the point of view of soil and cement consolidation to reduce seepage to a minimum.

A Field Method of Determining Clay Content of Soils.

The clay fraction is the most important constituent of soil and its estimation in a simple way which could be adopted as a field method, has been under examination. The Chemo-Hydrometer,

described in the previous report is the most suitable apparatus for the detailed examination of the mechanical composition of soils. It is, however, essentially a laboratory method, with limited application in the field. As the detailed mechanical analysis is not needed for most purposes, the development of a field method by which only the clay fraction could be estimated was considered desirable.

The turbidity of a clay suspension has been used as a measure of its concentration. The well-known nephelometer method consists in comparing the turbidity of the unknown suspension with that of the standard. As this apparatus is too elaborate it is not suitable for field use. A simple method is to lower an object in a largely diluted clay suspension till it becomes invisible to the eye placed at a certain distance above the suspension. A standard clay suspension can be used for calibrating such an apparatus. The greater the concentration of the suspension the smaller will be the distance, 'd', through which the object will have to be lowered. There cannot, however, be any simple proportionality between the clay percentage and 'd' as the suspension with greater amount of clay would also scatter more light causing 'd' to be greater than it should be on the ground of greater concentration alone.

The Apparatus.

The apparatus consists of a thin steel wire about 1 foot long fixed at the upper end to a vernier scale and at the lower end to a small thin circular metallic disc about 1 inch in diameter with a hole in the centre. The disc is coated with white enamel on which a circle is drawn with black ink. The black circular line with white enamel as the background serves an excellent 'object' to be viewed. The vernier and scale are capable of two independent movements by means of two screws. One screw is adjusted till the disc just touches the surface of the suspension. The vernier scale then reads zero. The wire is then lowered gradually by working the second screw till the dark line becomes just invisible. The length thus lowered is read by means of the vernier scale.

Experimental.

In order to find the relation between 'd' and the clay content of a soil, varying concentrations (0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1.0 per cent) of a soil were prepared. The soil used contained 55 per cent of clay. In the proposed method, a one per cent soil suspension is prepared. The suspensions may be regarded as equivalent to 5.5, 11.0, 16.5, 22.0, 27.5, 33.0, 38.5, 44.0, 49.5, and 55.0 per cent of clay respectively in the original soil. The clay was separated in each case by pipetting 50 cc. of the suspension from 5 cms. depth after allowing the suspension to stand for 12 hours. This volume was then diluted to 500 cc., put into a wide cylinder, shaken, and the disc lowered into it. The value of 'd' was determined in each case and plotted against the clay percentage of the suspension (Figure 10). This curve serves as the basic curve for clay determinations.

In order to determine clay contents of soils, one per cent suspensions are prepared, the clay is separated and diluted in the above manner and the value of 'd' determined. The percentage of clay is read from the basic curve corresponding to the value of 'd'. Clay contents of a large number of soil samples were determined by the pipette method as well as by the proposed method.

The results, on account of space, are expressed in Table 4 as difference in the clay content obtained by the two methods against the number of soils showing the difference of that order.

TABLE 4.

<i>Difference in clay percentage as determined by the two methods.</i>		<i>Number of soils showing difference of this order.</i>	
4-5	4
3-4	8
2-3	12
1-2	29
0-1	49

SOURCES OF ERROR.

Errors with soils of high clay contents.

It would appear from the curve (Figure 10) that with soils rich in clay, the method becomes less sensitive. It has been found, however, by experience that the point at which the 'object' becomes invisible in such cases is very sharp and 'd' can be determined with a great degree of precision. If desired the method may be modified by altering the dilution.

ERRORS ON ACCOUNT OF DIFFERENT COLOURS OF SOILS.

The colour of the suspension would appear at first sight to affect determinations by this method, but as the suspension is very dilute, the colour factor does not influence the results. In Table 4 the soils selected were of all the colours available. The agreement between the clay contents as determined by the pipette method and the proposed method shows that colour does not introduce an error.

The method can be used under field conditions with fair accuracy. Precautions such as lowering the disc in the middle of the cylinder, using similar types of cylinder, keeping eye always at approximately fixed distance above the suspension should be taken.

TABLE 1.

Showing the volume of soil at optimum moisture (12 per cent) after each stroke when the rammer is dropped from various heights.

Height in feet	1	2	3	4	5	6	7	8	9	10	12	14	16	18	20
0.20	132.0	121.3	116.0	113.4	109.6	107.1	105.2	104.0	104.0	101.8	100.8	99.2	99.2	99.2	99.2
0.75	123.8	113.4	107.1	104.0	100.8	99.5	97.6	97.6	97.6	97.6	.	..	..	..	..
1.00	120.0	110.0	104.3	102.1	98.3	98.3	98.3	98.3	98.3	98.3	..	..	..	..	..
1.25	113.3	105.5	102.4	99.2	98.3	97.6	97.6	97.6	97.6	97.6	..	.	..	..	..
1.50	118.2	107.1	101.8	99.2	97.6	97.6	97.6	97.6	97.6	97.6	..	..	..	..	..
2.00	111.8	101.0	100.8	99.2	97.6	97.6	97.6	97.6	97.6	97.6	..	..	..	..	..

TABLE 2.

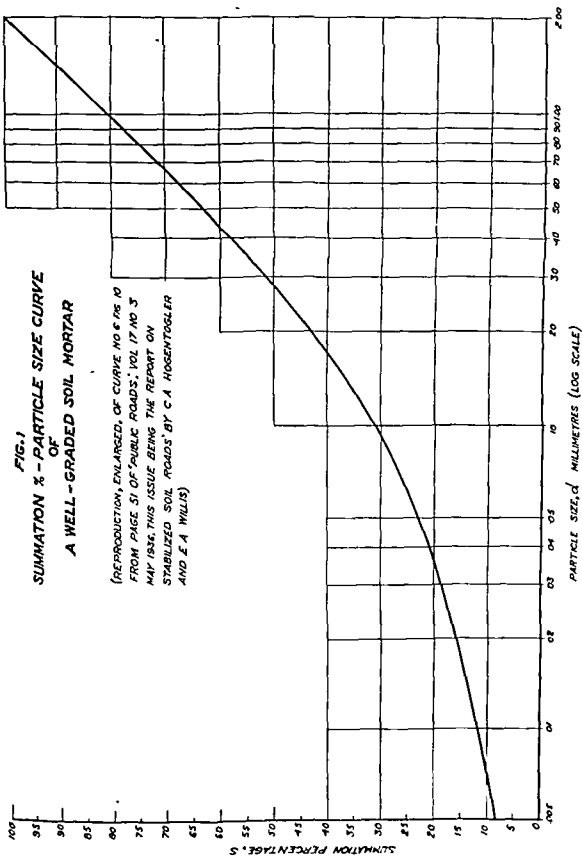
Showing the volumes from strokes of 2' height after each stroke at various moisture contents.

Volume in c

Moisture per cent	1	2	3	4	5	6	7	8	9	10	11	12
4 ..	125.5	119.7	114.4	113.7	112.5	110.9	110.6	110.0	109.6	109.3	109.3	109.3
8 ..	122.6	113.7	110.3	108.2	103.2	107.9	104.0	103.7	101.4	101.1	101.1	101.1
12 ..	114.7	107.7	104.0	102.1	100.2	97.6	97.6	97.6	97.6	97.6	97.6	97.6
16 ..	110.3	105.2	101.3	100.8	100.8	100.8	100.8	100.8	100.8	100.8	100.8	100.8
18 ..	110.9	106.8	104.8	106.5	100.8	106.8	106.8	106.8	106.8	106.8	106.8	106.8
18 ..	110.0	107.4	107.1	107.1	107.1	107.1	107.1	107.1	107.1	107.1	107.1	107.1

FIG. 1
SUMMATION % - PARTICLE SIZE CURVE
OF
A WELL-GRADED SOIL MORTAR

(REPRODUCTION, ENLARGED, OF CURVE NO 6 FIG 10
 FROM PAGE 51 OF 'PUBLIC ROADS', VOL 17 NO 3
 MAY 1936, THIS ISSUE BEING THE REPORT ON
 STABILIZED SOIL ROADS' BY C A HOSENTGGLER
 AND E A WILLIS)



SUMMATION % - PARTICLE SIZE CURVES

-- SOIL MORTAR (BEST GRADING)
 1 " (UPPER LIMIT FOR GOOD GRADING)
 2 " (LOWER " ")

REPRODUCTION, TO A BIGGER SCALE, OF FIG. 17,
 FROM P. 240 OF ENGINEERING PROPERTIES OF
 THE SOIL 1937, BY C. A. HOGENTGLER

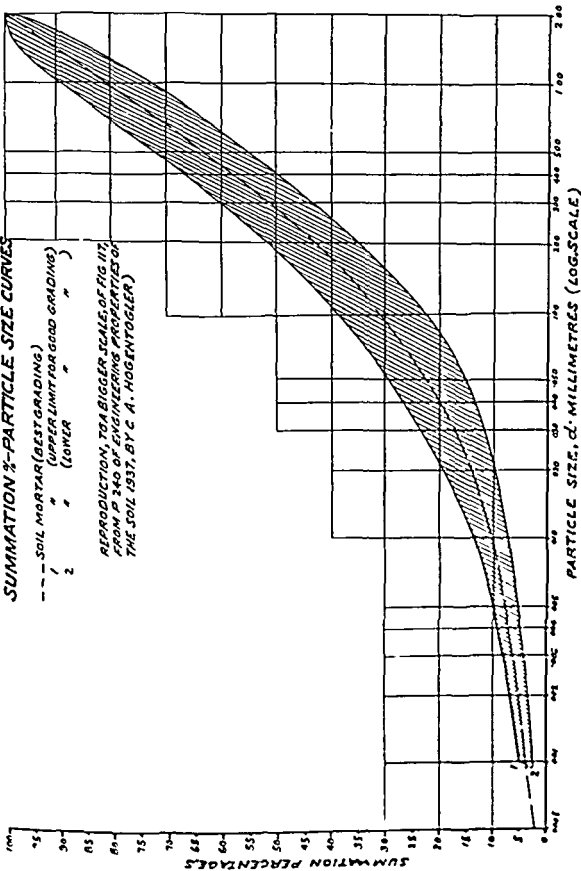
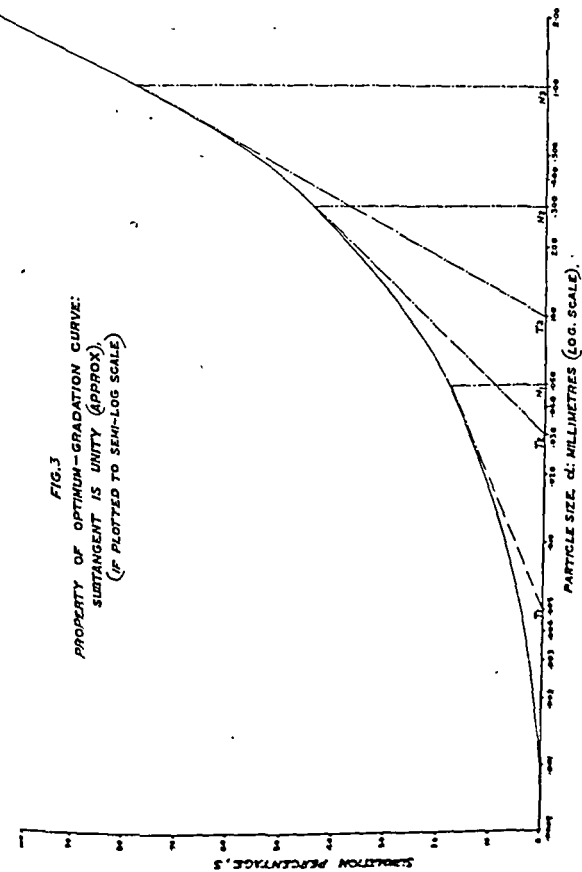


FIG. 3
PROPERTY OF OPTIMUM-GRADATION CURVE:
SUBTANGENT IS UNITY (APPROX),
(IF PLOTTED TO SEMI-LOG SCALE)



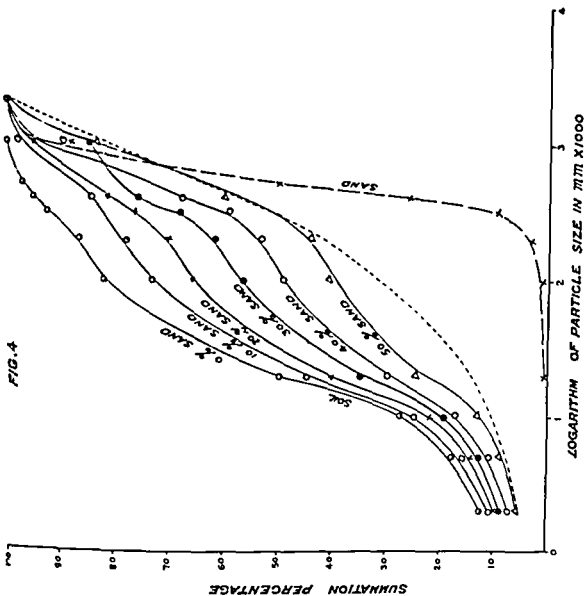


FIG. 5
RELATION BETWEEN DENSITY AND MOISTURE PERCENTAGE IN SOILS.

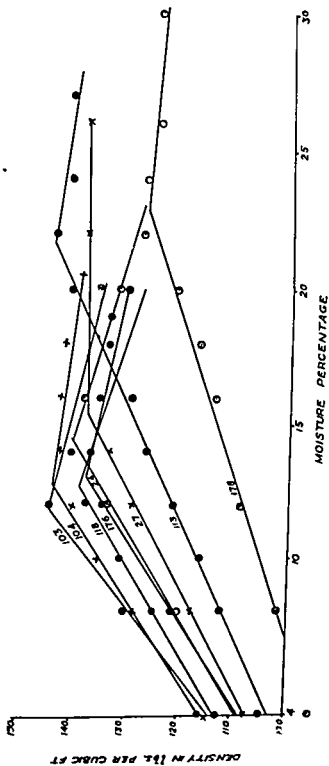


FIG. 7
EFFECT OF ADDITION OF SAND (0.537 CTRG. MEAN DIAMETER)
ON DENSITY OF SOIL AT VARIOUS MOISTURE CONTENTS

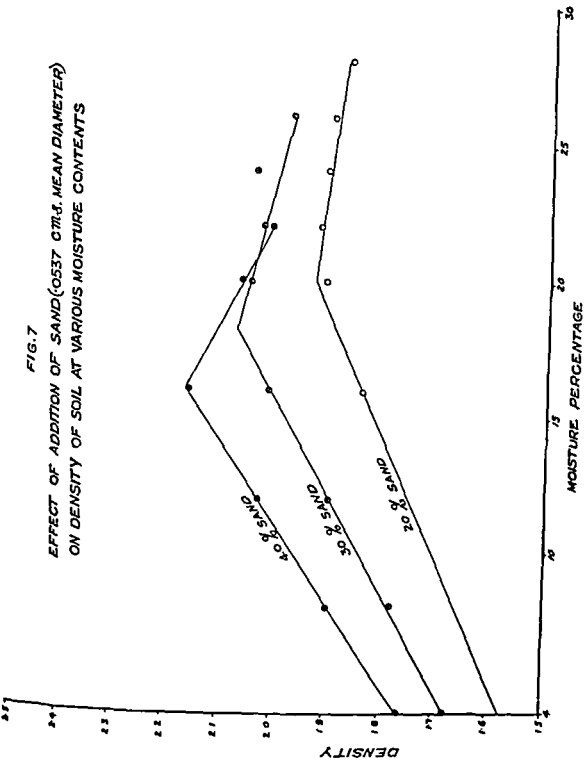


FIG. 8
SUMMATION CURVES OF TYPICAL PUNJAB SOILS

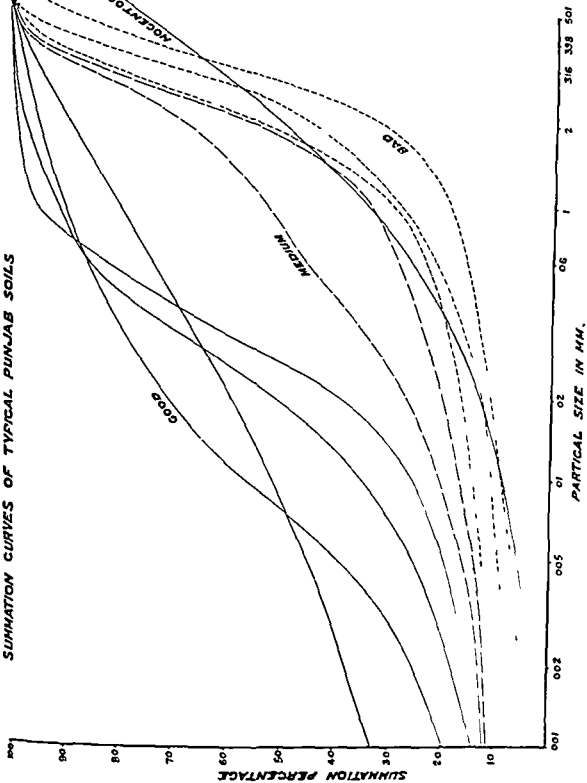


FIG. 9
RELATION BETWEEN CLAY CONTENT AND ROAD CONDITION

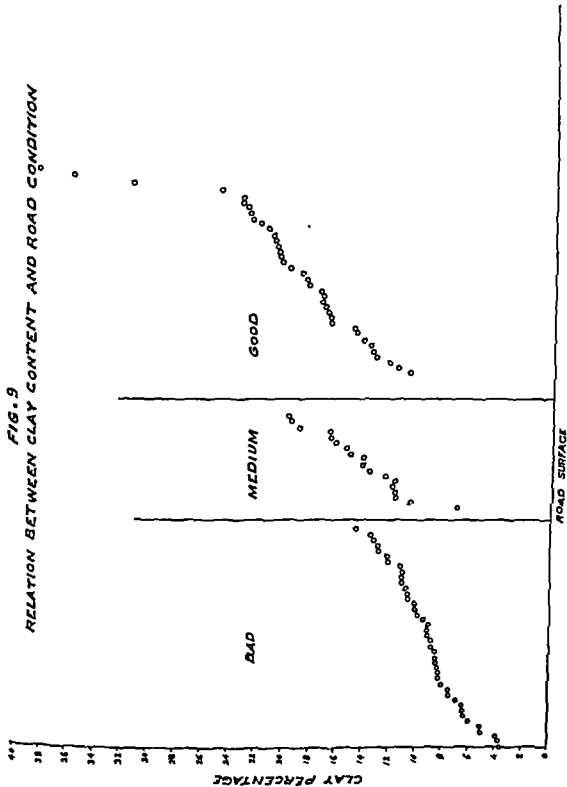
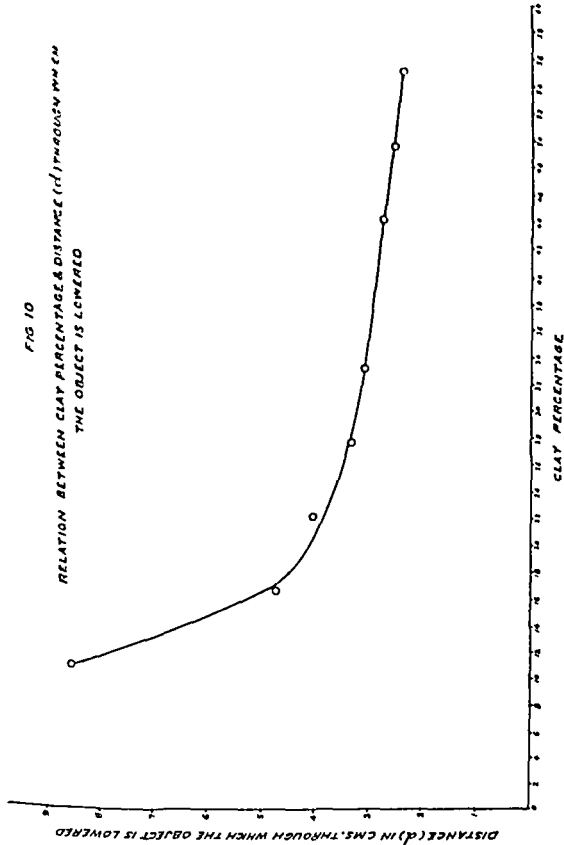


FIG 10

RELATION BETWEEN CLAY PERCENTAGE & DISTANCE (d) THROUGH WHICH
THE OBJECT IS LOWERED



PHYSICS SECTION.

The Detection of Cavities under Weirs by the Impedance Method.

It was reported last year that investigations on the detection of cavities under weirs by the vibrometer method were in progress at the Rasul Headworks. This method, however, has not been successful for two reasons; firstly, it was difficult to make the thick floor of a weir vibrate and secondly, where the masonry consisted of stonework, every stone vibrated independently of others, so that the vibrations remained confined to the surface of the floor and consequently could not reveal the conditions of the medium below. The method was, therefore, abandoned so far as the problem of cavity detection was concerned, but it was successfully employed in measuring the amplitude of the vibrations of the piers and the floor at Ferozepore weir caused by the passage of railway trains.

The solution of the cavity problem was attempted by a new method during the current year. Laboratory experiments had shown that the resistance of a column of sand saturated with water is independent of the grade of the sand but varies with the packing and quantity of sand present. This observation formed the basis of the method. The method depends on determining the resistance which the medium under a weir offers to the passage of alternating current between equidistant points.

The apparatus used consists of an a.c. source and a resistance measuring bridge equipment. The former is provided by a valve oscillator, the output of which is suitably amplified by a one-stage audio-amplifier, while the latter, which is schematically shown in Figure 11 consists of an adjustable resistance R , a resistance wire AB , a telephone T , and two special electrodes P_1 and P_2 .

The method of measurement is as follows. The electrodes P_1 and P_2 are brought in contact with the medium below the floor of the weir by introducing them through the grouting pipes which have recently been put in many of the Punjab weirs. R is now adjusted till its resistance is roughly equal to that between P_1 and P_2 . Finally the probe P is moved along the wire AB till there is silence in the phones. The required resistance is calculated by the usual ratio method.

The first set of experiments conducted in bay No. 2 of the Balloki weir have been completed. The plan of the bay showing the positions of the pipes along with the distances between them is given in Figure 12. About seventy measurements were made along and across the bay. The results are given in Figures 13 and 14. A study of the Figures 13 and 14 shows that the medium below the floor offers the least resistance to the flow of a.c. currents near the end of the sloping floor and a few feet above the inner toe of the subsidiary weir. While the maximum resistance met with is 613 ohms that between pipes

No. 38 and 39 in this region is only 276 ohms. Measurements along the bay shown in Figure 14 give indications of low resistance between pipes 34 and 35 also. It seems, therefore, that underneath this part of the weir marked in Figure 14, either the packing has become very loose or we may suspect the existence of cavities. These experiments are only in the preliminary stage and predictions cannot be made with absolute certainty, but the results are instructive and form a definite advance in our knowledge of the condition of the medium below a weir.

Experiments are now in progress in bays No. 1, 3, 30 and 34 of the Ballou Weir.

Capillary Forces in Natural Soils.

Early investigators had assumed that capillary forces in soil can raise water through considerable distances in fine soil from a water table. As the result of a series of investigations conducted by the Water-logging Investigation Circle it was concluded that the hydrostatic pressure in the capillary region above the water-table follows numerically the same law as below it. These conclusions taken together mean that the pressure distribution in the region up to many feet above the water-table is governed by simple hydrostatic considerations. The Physics Section, while collaborating with the Water-logging Investigation Circle pointed out that the technique of their experiments was not correct and that a great deal of confusion existed regarding the distribution of sub soil moisture and pressure. A series of investigations was started both in the field and the laboratory in order to elucidate these problems.

The first set of experiments was conducted to determine the negative pressures developed due to menisci formed at the air-water-sand interface in various types of soils and sands. The apparatus used is described below and is shown in Figure 15.

As the negative pressure exerted by a soil is a function of the particle size, these samples were mechanically analysed. Most of these analyses were carried by the optical lever siltometer and the results of these are given in Figures 16 and 17. The fine samples were analysed by the pipette method and the results are tabulated in Table 5. Two of the samples, however, were very coarse having a mean diameter of about one m.m. and, therefore, they could not be analysed in detail.

The next phase of the investigations was to determine whether the negative pressure developed is a function of the length of the sample column in AB, since under field conditions the soil column extends for some distance above the water-table. The apparatus employed was similar to that described earlier in this section, except that the length of AB was much greater. The experiments were conducted with two different specimens of sand and the results are given in Table 6.

TABLE 6.

Sand (a).

<i>Height of column in cm.</i>		<i>Negative pressure in cm. of water.</i>
5	..	24
20	..	25
31	..	23
50	..	22

Sand (b).

<i>Height of column in cm.</i>		<i>Negative pressure in cm. of water.</i>
5	..	32
20	..	33
31	..	31
50	..	30

The third phase of investigations arose out of the fact that under field conditions the moist soil is always covered with a dry layer. Experiments were, therefore, conducted to determine if the presence of a dry layer of sand in contact with the moist layer affects the value of the negative pressure developed in the sample. Two specimens of sand were again used, the length of the column in each case being less than the capillary height. The results are shown in Table 7.

sands due to capillary forces and when a constant height was attained, the readings were noted. These are given in column (3) of Table 5. From the analogy of simple capillary tubes the values of the negative pressure and capillary height should be the same, but a comparison of the columns (2) and (3) shows that the capillary rise is much greater than the negative pressure. This leads to the conclusion that the simple capillary hypothesis is inapplicable to heterogeneous soil aggregates.

The conclusions which can be derived from these investigations are :—

- (a) In very fine soils negative pressures as high as 562 cm. (approximately 19 feet) of water can be developed.
- (b) The negative pressure developed at the air-water-sand interface of a certain sample is independent of the length of the column of soil above it.
- (c) The presence of dry sand above the experimental sample does not affect the negative pressure values to any appreciable extent. In fact the effect is very small in comparison with the negative pressures developed in dry sand.
- (d) Contrary to what would be expected from simple capillary tube hypothesis, the capillary rise in a sample of sand is much greater than the negative pressure which it can develop, as the result of the formation of menisci at the air-water-sand interface.

The results of these laboratory experiments necessitated a thorough investigation of the problem of negative pressure in soils under actual field conditions. Experiments were, therefore, started in the field.

Field Experiments on Capillary Forces in Natural Soils.

These experiments were carried out with the help of the Roger's type of negative pressure measuring instrument. The essential features of the instrument are shown in Figure 18. It consists of a thick-walled cylindrical porous pot P made of a special mixture known as 'stone ware.' The ends of the pot are covered with brass plates B tightened together by means of a metal screw S. Between the covers B and pot P are rubber washers R, and T_1 , T_2 and T_3 are $\frac{1}{8}$ inch copper tubes. T_1 and T_2 end in screw caps C fitted with rubber washers, W, and are used to fill the pot P with water. T_3 has a rubber balloon RB attached to its lower end and is connected to the pressure gauge at its upper end. RB is partly filled with a 50 per cent air-free mixture of glycerine and water which effectively prevents freezing in cold climates. This device also prevents the air from entering the tube which would result in false readings. All the joints are made airtight by sealing with pressure wax.

to stand for 48 hours by which time an equilibrium between the water inside and outside the porous pot is attained and the manometer reading is noted.

Samples of the experimental soil are taken from A and the moisture content determined. The process was repeated with different soil moisture contents. A sample of soil having a PH of 9.3 and containing 18.18 per cent clay, 36.48 per cent silt and 45.76 per cent sand and a sample of sand, the mechanical analysis for which is given in Figure 22 were examined. Four different mixtures having different proportions of this sand and soil varying in steps of 20 per cent were studied. The results together with the composition of the samples are given in Figure 23.

It is apparent from the various curves given in Figure 23 that at low moisture contents the rate of decrease of negative pressure with increase in moisture content is very rapid. At high moisture percentages the rate of decrease of negative pressure slows down considerably, so much so, that the curves finally tend to become asymptotic to the moisture percentage axis. It is only in the case of sand that the curve touches the pressure axis at a moisture content of 25 per cent. Table 9 shows how the negative pressure varies with the composition of the sample at a particular moisture content. Thus at a moisture content of 10 per cent the original soil sample developed a negative pressure of 27.2 in. of mercury which gradually became less and less as the proportion of sand in the sample became more and more until, finally in pure sand it was only 1.8 cm. of mercury.

These investigations will be continued.

Laboratory Experiments on Water-Table and Negative Pressure.

tions have been made and the results are given in Figure 25. This figure shows that there is no region above the water-table where the hydrostatic pressure varies in a similar manner to that below it. In other words, the so-called saturated capillary region does not appear to exist in the mass of sand immediately above the water table to any appreciable magnitude.

From theoretical considerations of the capillary tube analogy it is tempting to assume that the region immediately above the water-table is completely saturated but the pressure measurements given above show that this is incorrect and thus prove that the simple capillary tube hypothesis cannot be applied to soil.

Field Moisture Capacity and Moisture Content.

In connection with certain experiments on field moisture capacity, it became necessary to determine the variation of moisture content in a sand column with height above the water-table and to find out how this distribution changed with time. Fourteen tubes, having wire gauze fixed to their lower ends were, therefore, packed with the same type of sand under water and allowed to stand over tubes containing water, so that the lower ends were dipping below the water surface. Every one of these tubes consisted of ten pieces of one inch bore glass tubing, ground at both ends and connected one above the other by means of rubber tubes. Now, as the tubes stand water is being evaporated from the upper regions and is being raised by surface forces from below. Thus a dynamic equilibrium becomes established between the two processes. To determine how this equilibrium distribution of moisture varies with time, one composite tube was dismantled at the end of each month and the moisture content in each of the ten sections determined. The results are given in Table 10.

A glance at the table shows that up to a height of about 18 inches from the water-table the moisture content was almost constant in all the tubes, but above it there is a rapid decrease. Thus, there is a distinct break from one zone to the other. Further, the moisture distribution does not seem to be appreciably affected by time, for there is no marked difference between the moisture content data obtained at the end of the first and the sixth months.

Evaporation, Drainage and Water-Table.

Keen, at the Rothamsted Experimental Station, carried out an experiment over eight years to study the effect of evaporation on the position of free water table in an initially saturated soil. The long period required for such experiments necessitated that some quick method of investigating the problem should be developed. The phenomenon also needed a thorough investigation especially in the light of the experiments carried out in connection with the abnormal rise of wells with small showers of rain. Experiments were, therefore,

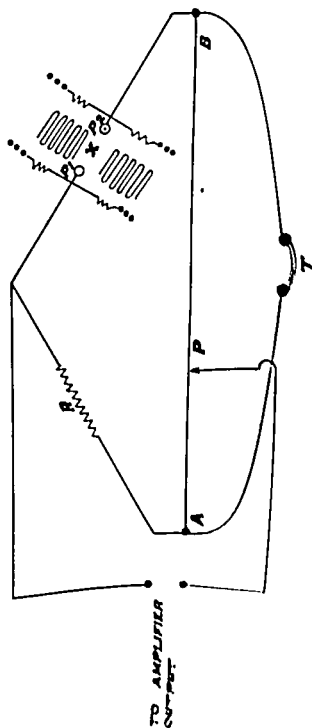
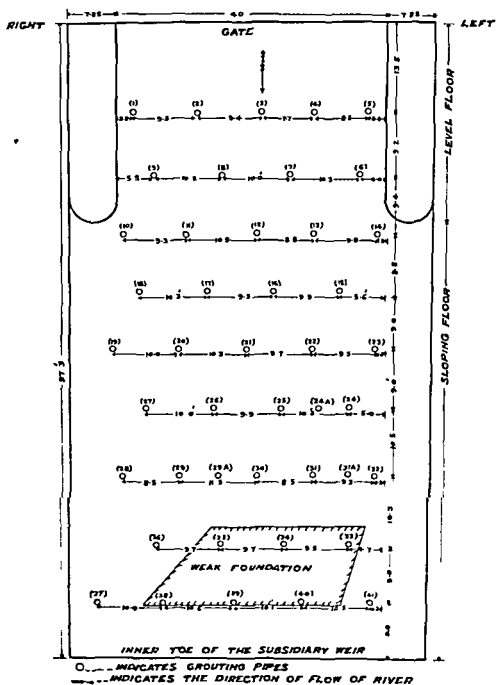


FIG. 12
BALLOKI WEIR
PLAN OF BAY NO. 2 SHOWING THE POSITION OF PIPES



ARRANGEMENT TO DETERMINE NEGATIVE PRESSURE IN SOILS

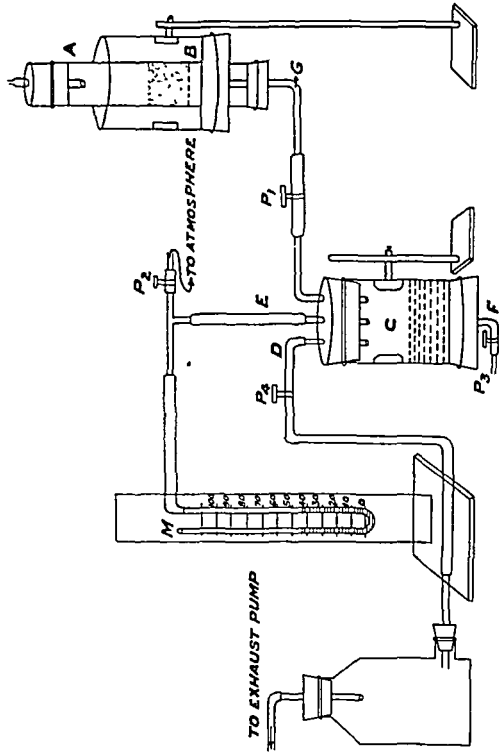


FIG.16
SIZE DISTRIBUTION OF SANDS
N_o 3 TO 8

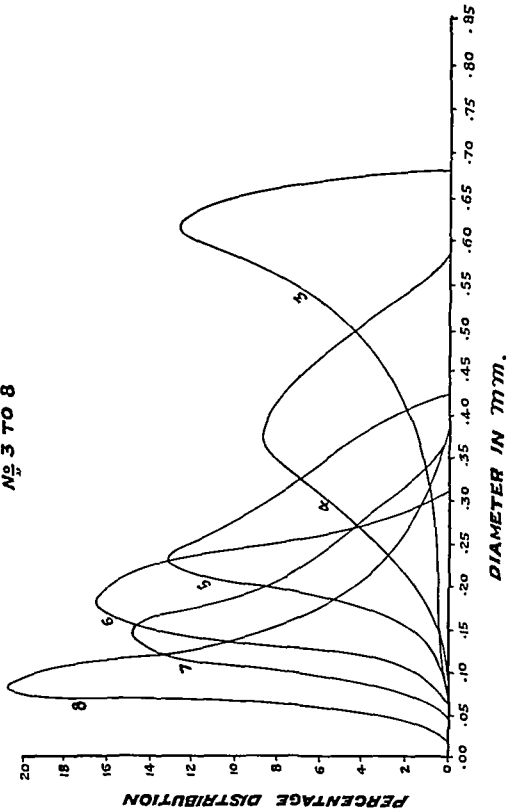


FIG. 17
ANALYSIS OF SILTS

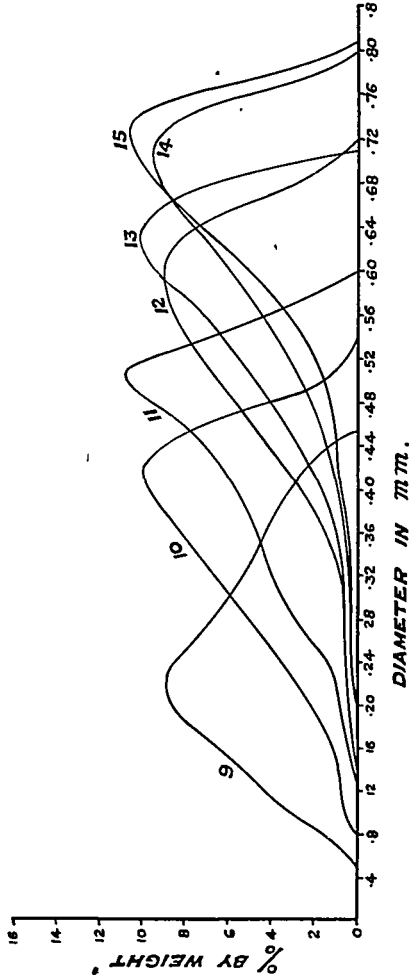


FIG 19
NEGATIVE PRESSURE IN FIELD AT VANIKE

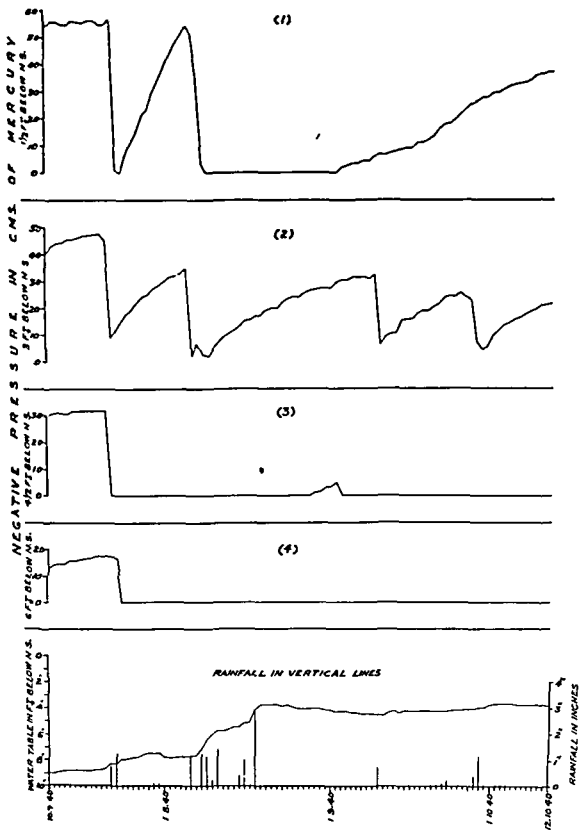


FIG 20
NEGATIVE PRESSURE IN FIELD AT CHIANWALI

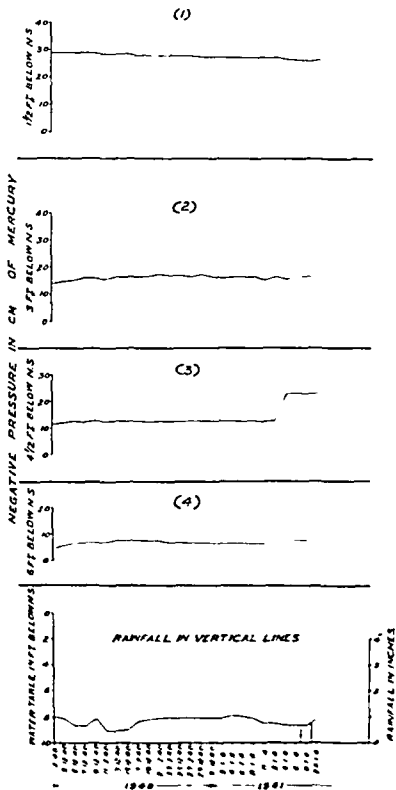


FIG. 21

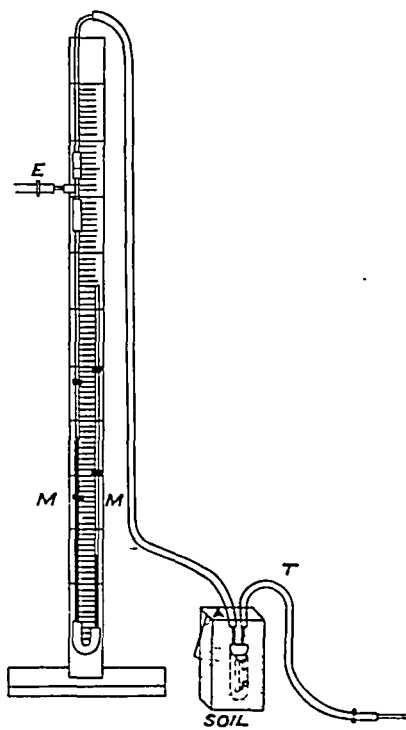


FIG. 22
SIZE DISTRIBUTION CURVE

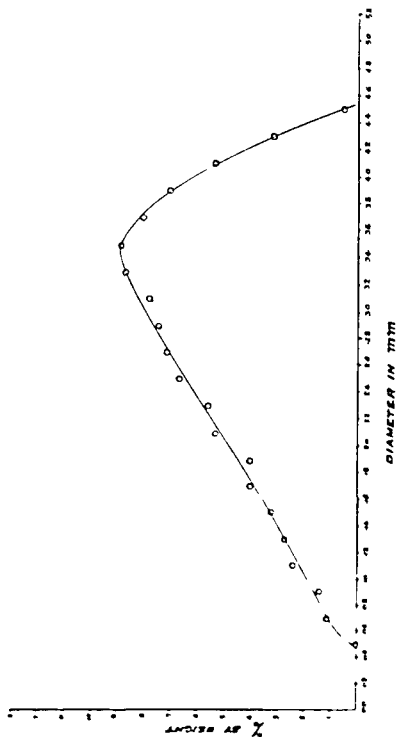


FIG. 23

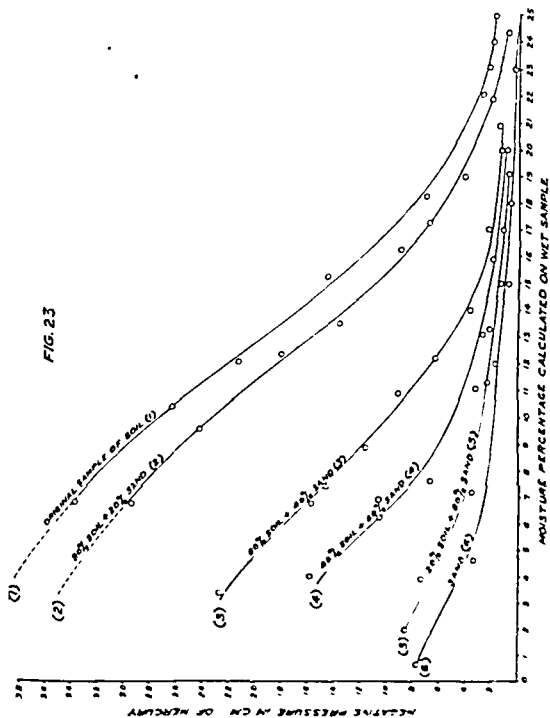


FIG.24

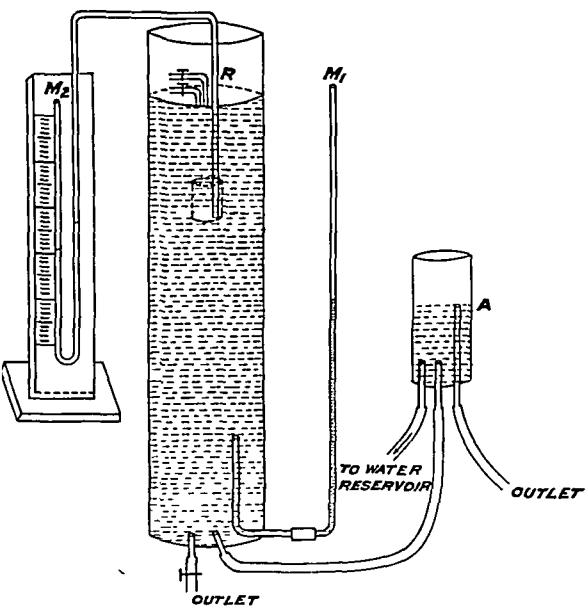


FIG. 25

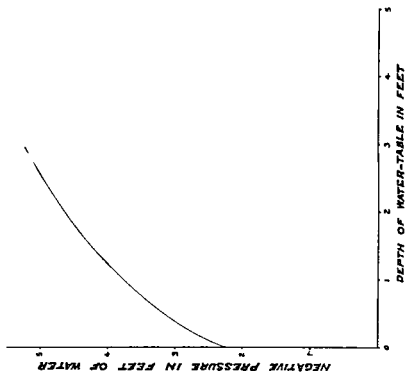


FIG.2 6

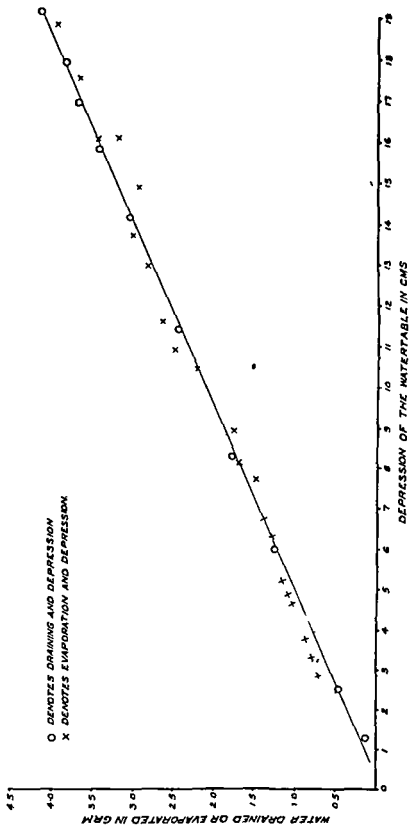


FIG. 27

APPARATUS FOR WATERTABLE AND EVAPORATION

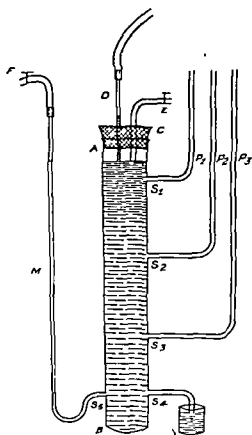
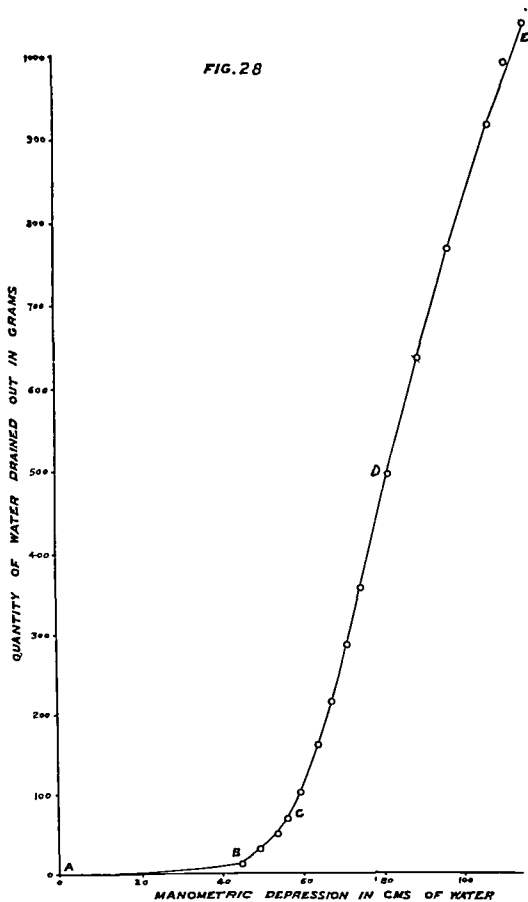


FIG. 28



○ DENOTES DRAINING AND DEPRESSION
 X DENOTES REFILLING AND RISE

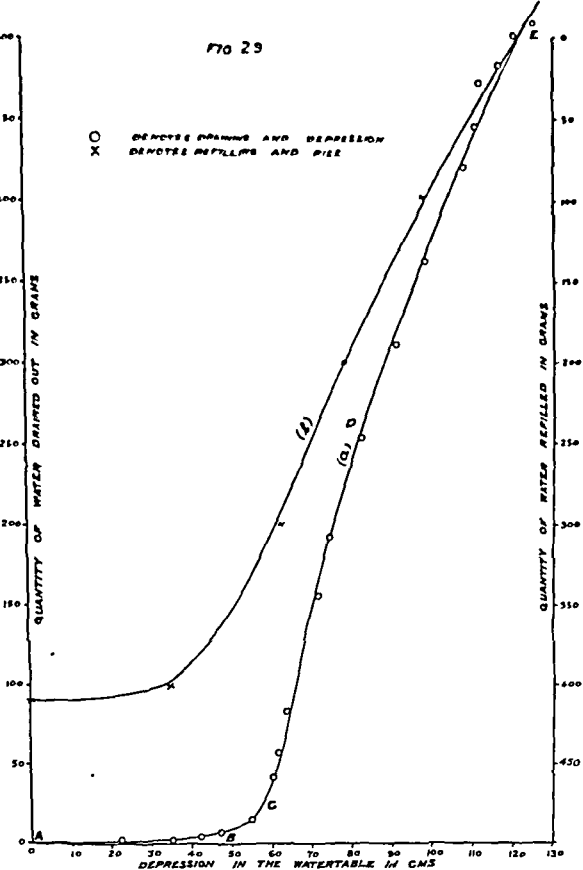
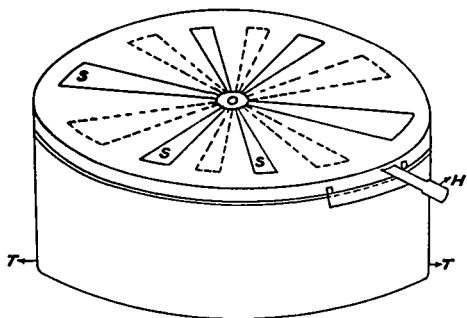


FIG. 30
SILT DROPPER



MATHEMATICAL SECTION.

Report on the silt surveys of Lower Chenab Canal during the year 1938-41.

The Chief Engineer in his letter No 1079, dated 8th June, 1937, ordered that a silt survey of Lower Chenab Canal may be started. In this letter he states —

“I agree that the changes in regime brought about by the construction of the silt excluder at Khaniki are not yet very serious or sufficient to cause alarm. In consequence the construction of special works, such as a silt ejector at Chenawan, a silt divide wall at Sagar, or silt clearance of the branches or distributaries are not as yet called for. All that appears to be necessary at present—and this appears of the utmost importance—is that a close contact over the regime of the various channels particularly of the Main Canal and Branches should be arranged.” It was therefore decided to start a silt survey of the main channels of Lower Chenab Canal System (Figure 31)

This work was actually started in June, 1938. It consisted of—

1 Half yearly silt surveys carried out generally during the months of June July and October November each year. They were carried out by two overseers. In these surveys the following information was collected :—

- (a) A bed sample from the centre of the canal at every mile
- (b) A water sample at the same place from the central vertical at 6D
- (c) Water surface width and central depth at the same place
- (d) Mile gauge reading

2 Monthly survey conducted on the above lines for Upper Gugera Branch in the East Circle and Dhaulgar Distributary in the West Circle

3 Direction of flow observations u/s of the regulators at Sagar, Nanuan and Buchiana. These observations consisted in finding the direction of flow of the bottom, middle and top currents at a number of points arranged in a grid system upstream of the regulators

4. *Bed silt experiments in Hafizabad Distributary*—This work was done for the West Circle only

It will be seen that these surveys were started to follow the changes that were taking place in the canals of Lower Chenab Canal system due to the construction of silt excluder tunnels at Khaniki

headworks. It was early recognised that the admission of comparatively silt free water into Lower Chenab Canal at Khanki will induce scouring. This has been amply verified by observations in the Main Line between Khanki and Sagar. (See Figure 32.) All the silt thus scoured has been carried down into the two branches that bifurcate at Sagar, i.e., Main Line Lower and Upper Gugera Branch. During last canal closure all the branches below Sagar were inspected. The condition of the bed and berms in these cases are given below.

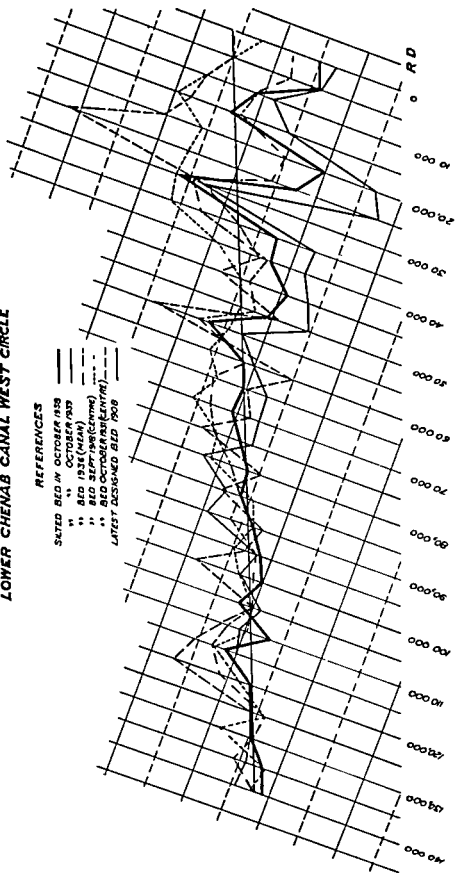
Upper Gugera Branch.—This branch takes off from the Lower Chenab Canal Main Line at Sagar. Upstream of the regulator there is a silt divide wall about 3 feet high covering the whole of the Upper Gugera Regulator. In the head reach of this branch up to R. D. 4,000 signs of a previous lining of the canal by means of stone ballast of the size of about 1 foot are present. The canal having widened considerably since it was constructed the original berms lined with ballast form submerged slopes in the bed about 5 feet high from the central bed on either side of the central line. Between the top of these old berms and the top of the new berms there is about 10 feet of raised bed filled with sand on either side. This canal throughout its whole length from Sagar to Buchiana runs through kallar soil and in consequence the berms slope at a very flat angle. The bed of the canal is mostly in scour and there are very few signs of silt movement. This is shown by the absence of any silt waves.

Lower Gugera Branch.—The Upper Gugera Branch divides into Lower Gugera Branch and Burala Branch at Buchiana. There is an arrangement for proportional silt distribution at the head at Buchiana. Up to R. D. 121,000 Lower Gugera Branch the bed is remarkably even—silt waves scarcely 10 to 12 inches high are seen at regular intervals of about 15 feet. The berms are falling at many places and in most cases overhanging—the soil is stiff enough to stand vertical. Upstream of the fall at R. D. 121,000, higher silt waves between 12 inches to 15 inches are visible for a distance of one mile. Downstream of the fall again the bed becomes smooth as before till a mile upstream of the fall at R. D. 171,000 where the waves again become high. This continues till R. D. 218,000, below which all these regular silt waves disappear but large pits and dunes begin to appear. In some places these pits are 3 to 4 feet deep. The characteristics of the berms do not change very much. The channel was inspected up to R. D. 300,000 and no change noticed on the bed or berms.

Burala Branch.—Up to R. D. 170,000 the characteristics on this channel are more or less the same as those of Lower Gugera Branch. The silt waves are regular and of small height 10" to 12" up to R. D. 77,000; downstream of this point silt waves became bigger but after 90,000 they disappear and large pits and dunes became frequent. These are of the same type as was met with in the Lower Gugera Branch downstream of R. D. 218,000. They continue up to R. D. 170,000 when they again suddenly disappear and the bed becomes remarkably

FIG 32

**SILT SURVEY OF MAIN LINE
FROM R D 0 TO R D 140,000
LOWER CHENAB CANAL WEST CIRCLE**



smooth—only small ripples are noticeable. These continue up to R. D. 360,000. The berms are of the same type as in the Lower Gugera Branch but the soil contains more kallar.

Main Line Lower.—The Lower Chenab Canal Main Line Upper continues beyond Sagar as the Main Line Lower. In this stretch, the bed level is all below spring level. The berms are falling in everywhere due to poor soil and kallar. The angle of repose of the soil is small. The berms cannot stand at a steep angle. There is no noticeable evidence of silt movement on the bed.

Mian Ali Branch.—At Nanuana the Main Line Lower divides into three branches of which the Mian Ali Branch is the extreme left. There is a silt divide wall between 2 to 3 feet high upstream of its regulator. In spite of this, this channel shows unmistakable signs of silt movement—silt waves are regular from head to tail and are about 8" to 10" high. There are overhanging berms at many places but falling berms only at a few places. This is due to berm trimming. The soil is good excepting at a few places where there are signs of kallar. At R. D. 63,000 there is a diversion channel which has trapped a considerable quantity of silt and, in consequence, the bed is free from silt waves for a distance of some miles downstream.

Rakk Branch.—In the head reach there is very little evidence of silt movement—silt waves are small, not more than 8" to 10" in height. In the tail reach below 200,000 there are no silt waves—not even ripples. The bed is remarkably smooth. There are falling berms and at places overhanging berms too. There are traces of kallar here and there but not very wide-spread.

Jhang Branch, Upper and Lower.—There is no evidence of silt movement in the head reach but below R. D. 69,000 silt waves appear. They are about 4" to 6" high and spaced at regular intervals between 15 to 20 feet apart. The channel continues in this manner as far as the tail of the Jhang Branch Upper. In the head reach where the soil is full of kallar, the berms are falling and sloping at a flat angle, but lower down where there is little kallar the berms are more or less in good condition. Only at few places was serious berm erosion noticeable. In Jhang Branch Lower the silt waves increase in height to 8" to 10" otherwise there is no change—the berms are better here.

It will now be seen later how these observations about the conditions of the bed and berms of the canal while dry can help in arriving at a correct estimate of silt deposition and silt movement in the different branches. Analysis of the data shows that silt movement and silt deposition are two distinct phenomena connected with canals. If a canal is getting an excessive quantity of coarse silt at its head and if this silt is of such a nature that it is likely to become bed silt in the canal, then this channel will start sloping if the slope is not enough to carry the extra quantity of silt on the bed or if the slope

In Table 12 to 21 bed silt diameters and discharges in the different stretches of the branches have been tabulated and the calculated value of the water surface slope, obtained from

$$S \times 10^3 = 2.09 \frac{m^{.86}}{Q^{.21}}$$

and the actual slopes over the reach have been given. Each reach of the system has been examined with reference to Table 12—21 and Figure 33. Results will be given here in brief:—

Main Line. Upper and Lower.—Table 12.—In the head reach up to R. D. 43,000 the bed has scoured heavily and the slope has become excessively flat. In the reach between R. D. 40,000 and R. D. 75,000, the bed has almost stabilized itself and the proper slope has been reached. Proceeding lower down, the actual slope becomes steeper and steeper indicating that the silt scoured from the upper reaches is still to be found in these reaches. This was also verified by closure observations.

Jhang Branch Upper.—Table 13.—Here the slopes are everywhere steeper than the calculated ones and point to rapid silt movement on the bed. Figure 33 shows that very little silting should take place now. This was verified by closure observations.

Jhang Branch Lower.—Table 14.—Here also the slopes are everywhere steeper than those calculated and Figure 33 indicates that there is very little silting excepting in short stretches. Closure observation shows regular silt movement in the bed.

Rakh Branch.—Table 15.—Here the slopes are almost the same as those calculated—so that very little silt movement could be expected. Closure observation confirms this. Figure 33 points to heavy silting but, due most probably to the quantity of silt entering being very small, no appreciable silting is noticed. Upstream of the regulator at Nanuana there is a silt divide wall covering the whole of the regulator of this branch. This may be the reason why a very small quantity of coarse silt is entering the canal.

Mian Ali Branch.—Table 16.—Here the slopes are steeper than those calculated and closure observation showed silt movement on the bed. Figure 33 points to very little silting.

Upper Gugera Branch.—Table 17.—In the head reach the slopes are almost the same as required by the Institute formula

$$S \times 10^3 = 2.09 \frac{m^{.86}}{Q^{.21}}$$

Up to R. D. 95,000 the required slopes have been attained by scouring; lower down the actual slopes are steeper than the required indicating

silt is put to make it flush with the natural silted bed of the distributary. On the top of each of these trenches a pair of N. G. rails runs across the distributary. These carry a trolley from which soundings of the deposition of silt in the trenches (when open) are recorded. A series of experiments on the deposition of silt in these trenches has been carried out. A complete report will be submitted later.

"Lacey's "Theory of Shock" and Regime of Channels in Alluvium.—It is possible to conceive of "Stable channels in incoherent alluvium" which will be subject to no extra disturbances from the boundary excepting those generated by the incoherent alluvial nature of the wetted perimeter. This definition is based on the analogy of "flow in smooth pipes". Though rigorously it is not possible to have an "absolutely smooth pipe" yet with a laminar boundary layer it is possible to conceive of a "perfectly smooth pipe" and to apply the Prandtl-Karman equation of turbulent flow for such pipes. Mr. Lacey is of the opinion that, similarly, in the case of "stable channels in incoherent alluvium", it is possible to conceive of turbulent fluid flow undisturbed by any outside disturbances (Shock or Coherence). The wetted perimeter will consist of incoherent alluvium and will adjust its shape to internal impulses received from the body of the fluid. The boundary is assumed to be flexible and self-formed. Mr. Lacey further assumes that his 'regime equation'

$$V = 16 \sqrt[3]{R^2 S} \quad (1)$$

applies to such channels only.

In Chapter IV of his latest publication "Regime flow in incoherent alluvium" Mr. Lacey shows how equation (1) was derived by him. "The writer (Mr. Lacey) in the derivation of his equation selects first a characteristic group of channels (Appendix C of Mr. Lacey's Publication) of very widely varying materials in order to arrive at a provisional solution, and tests the provisional relationship subsequently by plotting the entire mass of data available".

"The most convenient method of testing this equation is to plot to a logarithmic base values of V and values of $R^2 S$. In Appendix D (of Mr. Lacey's publication) are given data for a large number of channels in *approximate regime*. In Appendix E (of the same publication) are given hydraulic data for rivers and *torrents* in *quasi regime*".

"The entire data have been plotted by the writer (Mr. Lacey) in Figure 4, and demonstrate that the general regime equation $V = 16 \sqrt[3]{R^2 S}$ fits the data with accuracy."

In a note on Verification of Lacey Regime Formula $V = 16 \sqrt[3]{R^2 S}$ submitted to the Central Board of Irrigation in July, 1940, Dr. Malhotra has also analysed these data statistically and arrived at the following conclusion:—

"To sum up, it appears that while the Lacey Regime Formula is fairly well satisfied by the data on which it is based, the slight

The Punjab Irrigation Research Institute carried out the analysis statistically on 42 Punjab Canals and obtained the following :—

$$V = 1.12 R^{\frac{1}{2}} \quad \dots \quad \dots \quad \dots \quad \dots \quad (5)$$

$$P_* = 2.6 Q^{\frac{1}{2}} \quad \dots \quad \dots \quad \dots \quad \dots \quad (6)$$

$$S \times 10^3 = 2.09 \frac{m^{.86}}{Q^{.21}} \quad \dots \quad \dots \quad \dots \quad (7)$$

The above equations have been derived in the same way as

Lacey's Regime Equation $V = 163 \sqrt{R^2 S}$ and if the Regime Equation applies to "Shock" free Regime channels, these equations should also be applicable to regime channels free from "Shock".

The method employed in arriving at Equations (1) to (7) is the method of least squares that has for a long time been used for assigning the values to be taken when there are a number of inexact measurements at choice.

Suppose a quantity z to be related to k unknown constants x_1, x_2, \dots, x_k by the equation $z = u_1 x_1 + u_2 x_2 + \dots + u_k x_k$ where u_1, u_2, \dots, u_k are quantities that can be observed; and let n sets of observations be made giving

$$1^z = 1^u_1 x_1 + 1^u_2 x_2 + 1^u_3 x_3 + \dots + 1^u_k x_k$$

$$n^z = n^u_1 x_1 + n^u_2 x_2 + n^u_3 x_3 + \dots + n^u_k x_k.$$

Mr. Lacey in C. B. I. Publication No. 20, Chapter V, page 14 has defined "Shock" as being due to bends or irregularities in the channel and also due to channel condition as opposed to channel material. Further in Chapter IX, page 29, he has given a graphical representation of Shock (Figure 11) which has been subsequently converted to a mathematical form by Dr. Malhotra.

$$\% \text{Shock} = 90 \sqrt{2} \log(C_L).$$

$$\text{where } C_L = \frac{V}{16 \sqrt[3]{R^2 S}}$$

To see if these three definitions of "Shock"

- (1) as an error of random sampling,
- (2) as being due to bends, irregularities or channel condition,
- (3) expressed as $\% \text{Shock} = 90 \sqrt{2} \log(C_L)$

are self consistent or not a detailed and extensive survey of the regime sites of the Punjab was undertaken during the months of November—December 1940 and January—February in 1941. The channels were all in closure during these periods and the beds could be inspected dry. All the sites that had been under observation since September 1933 were re-visited and the following information collected:—

- (1) Cross sections of the canal at the observation sites and at every 100 feet upstream and downstream of the sites for a distance of 1,000 feet on either side. R. L. of the natural surface was also taken at the same time to record if the channel was in filling or digging.
- (2) Bed silt samples at the centre of the cross section and soil samples from both the berms at each one of these cross sections. These were taken to see if the erosion of the berm was due to poor soil or not.
- (3) Information about full supply discharge and slope were obtained from local divisions.
- (4) Photographs of the berms and the bed at representative points of the canal near the site were taken.
- (5) Sketch plans were prepared showing respective position of the sites at every centre noting the water level, bed level, discharge of the parent channel and off-taking channels on which the observation sites are situated. Notes were also taken of the arrangement of the regulators and their crest levels and also of the methods of regulation practised.

Excepting for one or two cases the channels were found in the same condition as when observations on them were discontinued.

Hydraulic data of these channels as obtained during the periods of observation have been tabulated in Table 20. Along with the observed data, the values for S , R and P , C_L and % shock have been calculated from the following equation:—

$$S \times 10^3 = 2.09 \frac{m^{.86}}{Q^{.21}}$$

$$R = .47 Q^{\frac{1}{3}}$$

$$P = 2.8 Q^{\frac{1}{2}}$$

$$C_L = \frac{V}{16 \sqrt[3]{R^2 S}}$$

$$\% \text{ Shock} = 90 \sqrt{2} \log (C_L)$$

and tabulated.

Some of the channels have been re-grouped according to different degrees of shock and tabulated in Table 21. Photographs relating to these sites are given in Figures 34—45.

Group I.—Here are two channels for which the percentages of shock are almost equal though Figures 34 and 35 will show that the physical characteristics of the two sites are totally different. Both sites contain sand on the bed.

Group II.—All the three sites belong to the Lower Gugera Branch; they have more or less the same degree of shock. The upper site shows evidence of regular silt waves about 10" to 12" high spaced at intervals of 20' whereas both the lower sites show no regular silt waves—instead the bed is full of sand dunes and pits as high as 3 feet. Movements of bed silt in the lower sites are much heavier than at the upper site.

Group III.—In this group there are three channels that exhibit very little shock; as a matter of fact one of the channels is almost the ideal channel showing only —0.6% shock. This channel shows irregular silt waves even dunes and pits. The other two sites do not show any silt waves or ripples though there is 1 to 2 feet of silt on the bed.

Group IV.—All the channels in this group exhibit negative shock. Figure 42 shows the condition of Khurrianwala Distributary. It has a lot of staking and bushing though it exhibits the greatest degree of negative shock. All the channels have sand on the bed between 1 to 2 feet deep. The berms contain fine silt.

The values of slopes and wetted perimeters, actual and calculated from equations (7) and (6), are also given in Table 21. With the exception of a few cases, the agreement is quite good.

Summary—The above analysis and survey show that—

- (1) "Shock" cannot be looked upon as an error of random sampling. It is a physical characteristic of the channel involving irregularities of bed and berms and probably also depends on the quantity of silt rolling on the bed of the channel. Hence, two channels apparently dissimilar in berm and bed irregularities may have the same percentage of shock, as in Group I, due to the extra quantity of bed silt which the channel may be forced to carry.
- (2) The percentage of shock as given by $90\sqrt{2} \log (C_L)$ does not represent correctly the channel condition. Channels in Group IV according to this formulæ exhibit negative shock which according Lacey (C B I Publication 20, page 27) should be due to major irregularities in the channel such as smooth portions of the banks of stiff fine clay and also possibly smooth rigid patches of the bed. This is not satisfied by Khurrianwala Distributary (Figure 42) and Rakh Branch R D 213 800 (Figure 43) so far as the berms are concerned. There is 1 to 2 feet of sand on the bed of all the channels so that the second condition about the bed is also not satisfied.

Report on the effect of drains on the seepage from Canals—These experiments, started in 1938, were designed to determine the effect of the presence of the Rechna Drain on the seepage from the Upper Guger Branch which run parallel to each other at a distance of about 1,040 feet. During the year 1938-39 the reach of the drain between R D 70,000 and 65,000 was investigated and it was found that at this distance the presence of the drain was not increasing the seepage from the canal. During the year under review these experiments were repeated for the stretch of the drain between R D 65,000 and 56,250. In this stretch the distance between the canal left berm and the drain is about 1,000 feet. Three lines of pressure pipes were installed at R D 62,500 (D—line) 60,000 (E—line) and 57,500 (F—line). These lines run at right angles to the drain and to the canal. In each line there are twenty five pipes, seven pipes on the right bank of the canal, the farthest being 1,000 feet from the canal, twelve pipes between the canal and the drain and six pipes on the left bank of the drain. The lay out is shown in Figure 31. At R D 62,500 the R L of the bed of the canal is 680.69, and that of the bed of the drain 680.65 at R D 60,000 the R L of the canal bed is 680.35 and that of the drain bed 681.20 and at R D 57,500 the corresponding figures are 679.96 and 678.98. The water surface width of the canal is 160 feet and that of the drain is about 15 feet.

After the pipes had been installed a canal closure from 15th December 1939 to 8th January 1940 took place. During this closure

the watertable fell and the observations taken are given in Table 22. These show there was a slope in the water-table from the drain to the canal. As the water-table crossed the canal which was working as a drain during closure, there was a drop in the water-table across the canal of the order of 0.10' along D line, 0.25' along E line, and 0.2' along F line.

Variable supplies were run in the canal until 27th February 1940 when it became steady and observations were taken on 2nd March 1940 which are given in Table 23. The rises in spring level compared with the resting levels on 8th January 1940 are given in Table 24. From this table it will be seen that the differences in rises over the resting levels on 8th January 1940 on the left and right of the canal along the D line can be accounted for by the drop in the resting spring level as the D line crossed the canal. Along E and F line, the rises in the spring level are more on the right than on the left of the canal even if the drops in the resting spring levels of 8th January 1940 across the canal along these lines are taken into consideration. Along D line the rise in the spring level on the left of the canal was of the same order as that on the right whereas along E and F lines the rise on the left was less than that on the right.

Now the resting water-table in this stretch has a slope from the drain to the canal, i.e., from the left of the canal across it to the right. If on this sloping water-table seepage from a canal is superimposed then the rise in the water table on the left of the canal will be greater than that on the right. If the water-table had been horizontal and the seepage from the canal were superposed on it then the presence of a drain on the left would reduce the rise in the water table on the left as compared to the rise on the right. Hence, the existence of a slope in the water table introduces a rise in the water table on the upstream side while the presence of a drain reduces it.

In the present case along D the above two effects counteract each other so that the influence of the drain is small as compared with the effect of the sloping water-table. But along lines E and F the influence of the drain appears to predominate over that of the sloping water-table. To find out to what extent this was the case these investigations were extended to eliminate the effect of the drain. This was done by constructing earthen walls in the drain so as to divide it into compartments and to allow the water to head up. These compartments were made such that the lines of observation pipes D, E and F crossed the centres of their respective compartments. The construction of the compartments was done on 18th March 1940. The water levels in the drain and the pipes rose but they did not become steady still 17th April 1940 as the supply in the canal had been fluctuating considerably. Table 25 gives the water levels on 17th April 1940.

From Table 25 it will be seen that the canal supply level rose by 0.67 feet between 2nd March 1940 and 17th April 1940 when the

supply became steady. This rise would introduce a rise of about 10 feet in pipe No. 1 (See 1938-39 Report of the observations on pipe lines, A, B and C, in this connection.) Instead of a rise, water levels in the pipes on the right of the canal away from the influence of the drain went down by 0.4 feet in D line, 0.38 feet in E line, and 0.58 feet in F line. This must be due to a general drop in the water-table during this period. This general drop in the water-level in this area may be taken to lie between 0.43 feet to 0.68 feet from 2nd March, 1940 to 17th April 1940. If now the general water-table is raised by 0.5 feet along D line, .43 along E line and .68 along F line, then the water levels in the pipes between the canal and the drain (Pipes Nos. 9 to 19) will be raised to different amounts. These rises in D line will be of the same order as the rise in the canal level in this period. Along E and F lines, these rises will be more than the rise in the canal level. The rises near to the drain are considerably higher but this is only natural as the presence of the drain when it was functioning as a drain had produced a draw-down which vanished as soon as the drain was closed.

Thus the presence of the drain between R. D. 63,750 and 61,210 does not affect the seepage from the canal, between R. D. 61,250 and 56,250 there are indications to show that the presence of the drain does affect the seepage from the canal.

Combining this year's data with the data from observations carried out during the 1938-39 it can be concluded that :—

- (1) Between R. D. 71,250 and 61,250 the presence of the drain does not affect the seepage from the canal.
- (2) Between R. D. 61,250 and 56,250 there are indications to show that the presence of the drain does affect the seepage from the canal.

In the reach between R. D. 71,250 to 56,250 the drain runs almost parallel to the canal at a distance of about 1,000 feet. The difference in behaviour between the two reaches (1) and (2) is most probably due to a difference in the soil lying between the canal and the drain.

This indicates that soil type should be taken into consideration in fixing the alignment of drains with reference to canals and that no hard and fast rule can be laid down for the distance between a canal and a drain so that seepage is not influenced by the presence of the drain.

1. *Comparisons of different types of suspended silt samplers.*—In order to obtain samples of suspended silts in canals and rivers the apparatus that is generally used is known as "Bottle Sampler". It consists of one litre bottle fixed to the end of a pipe with an external arrangement for opening and closing the bottle while it is under water. This bottle is held in a cage whose height is about 7 to 8 inches. In order to take samples of water, the sampler is lowered to a certain

depth, and then opened. Water enters the bottle and it takes generally 15 to 20 seconds to fill when the stopper is replaced and the sample is taken out. It has been contended that as the sampler catches water not from a filament of flow but from all sides, samples collected by it will not be representative. Attempts, therefore, have been made to devise an apparatus that will not be open to these objections.

Sampler No. 1.—This has been devised by Dr. H. L. Uppal of the Research Institute. It consists of a streamline body with a moveable diaphragm shutter. It is placed with its opening facing the flow.

Sampler No. 2.—This has been devised by Pandit Jagat Ram of the Research Institute. It consists of a rectangular box with a moveable rubber flap shutter. It is placed with its opening facing the flow.

Sampler No. 3.—This sampler was devised by Mr. Binkley of the United States Geological Survey and is used there extensively. It consists of a long brass tube (5" diameter 8" long). The tube is extended by attaching 6" length of motor car rubber tube on either end with two brass rings of the same diameter (5") at the two extremities. The sampler is closed by twisting these two tubes. The tube is placed along the direction of flow.

Sampler No. 4.—The sampler has been devised by Dr. A. N. Puri of the Irrigation Research Institute. It has no pretension to streamlining. It consists of two halves of a hollow sphere that are separated by means of a spring which can be released while taking samples. The sampler is lowered to a certain depth and the two halves are closed trapping the sample.

It was decided to compare the relative accuracy and efficiency of these five samplers. These experiments were carried out at R. D. 143,000 of Lower Chenab Canal Main Line Lower when the depth of water was 8.5 feet. A vertical about 70 feet away from the right bank of the canal was chosen and samples with different samplers were taken at 1D starting from the surface. The whole series of observations took about a week and they were conducted in the following manner. As each of the samplers contains about two liters, three fillings were taken and mixed together giving about 6 liters. The bulk samples was analysed for coarse and medium silt. In the case of the bottle samples six fillings were taken and mixed for analysis. First of all, one sampler (No. 3, Binkley sampler) was chosen and compared with the bottle sampler. At 1D a sample was taken with the bottle sampler and immediately afterwards a sample with Binkley sampler, then another sample with bottle sampler followed by a sample with Binkley sampler; this combination was repeated once again. Similar sets of 3 pairs of samples with the bottle sampler and samplers No. 1, 2 and 4 were repeated on the same day. The total time taken by

A proper comparison between the four samplers can be made by taking their differences from the bottle sampler. These are given below in milligrams per litre :—

Depth	Sampler No. 1.	Sampler No. 2.	Sampler No. 3.	Sampler No. 4
1D	8	62	40	37
2D	45	94	41	54
3D	49	103	27	53
4D	35	119	28	14
5D	42	110	—6	19
6D	—14	181	68	41
7D	30	126	33	71
8D	43	50	—2	30
9D	82	226	83	43

This table shows that sampler No. 4 gives the most consistent samples.

From Table 32 it will be seen that samplers Nos. 1, 3 and 4 are giving comparable values. The bottle sampler always gives higher values and sampler No. 2 always lower.

Conclusions.—From the above results it appears that it is not necessary to streamline the apparatus. Sampler No. 4 which is very far from being streamlined gives results that compare as favourably as any of those streamlined such as Nos. 1 and 3. This is because of the fact that due to turbulence in the canal water silt particles do not flow in streamlines; they are thoroughly mixed up in the body of the fluid, except very close to the bed; and, in consequence, it is not necessary to collect the samples in stream tubes.

It is important that a reliable sampler should have the following characteristics :—

I.—Reliability.—Correctly representing the quantity of silt in suspension. This is done by samplers Nos. 1, 3 and 4.

II.—Consistency.—Variation from the true value should be as small as possible. Samplers Nos. 2 and 4 give the least variations.

III.—Ease of Working.—The samplers should be easy to work. Samplers Nos. 1 and 4 are the easiest to work. According to the Overseer who worked these samplers, sampler No. 1 is liable to be damaged while working.

IV.—*Time and quantity of sampling.*—For field work it is important to have samplers that will take a short time to fill, and at the same time give a large volume of the sample. Sampler No. 2 is the best in this respect.

Considering all the above characteristics it appears that sampler No. 4 is the best. It will require the following modifications:—

- (1) The diameter of the sphere should be increased by 20 per cent so that the quantity of the sample will be about 4 litres.
- (2) The method of opening the two hemispheres should be altered to give more rapid opening.

A note on the efficiency of the Silt Excluders in the Left Pocket of the Headworks at Trimmu. (1939 summer.)

Silt observations at Trimmu Headworks were commenced in May 1939. They consisted of:—

- (1) Bottle sampling in the boils downstream of the undersluices gates—5 bottles in each bay of the under-sluices were collected and mixed together. This constituted one sample which was analysed for coarse (> 0.2 mm. diameter) and medium ($> 0.07, < 0.2$ mm.) silt.
- (2) Bottle sampling in the boils downstream of canal regulator—5 bottles in each bay constituted one sample. They were treated in the same way as in (1).
- (3) Bed samples were collected from the Haveli Main Line Canal at R. D. 1,000 twice a week and one bed sample from the left excluder pocket at R. D. 475 on some occasion. The mean diameters of these are given in Table 36.

Four samples from the four bays of the excluder left pocket were analysed separately and the means of the intensities of coarse and medium silt were taken. Similarly for the four non-excluder bays and the five canal regulator bays. These have all been tabulated in Table 33.

In a note on silt observation at Trimmu and Sidhnai Headworks sent to the Chief Engineer, it was remarked that "Apart from the question whether these boil samples give a representative sample for the whole bay or not, there is another difficulty in collecting samples from the boils of the tunnels. Sometimes the downstream water level is so low that no boil is formed and samples have to be collected from 0.6 D of the water flowing on the down-stream floor." During the summer of 1940 a set of parallel observations was arranged by taking bottle samples in the pocket upstream of each tunnel to test the representative character of the boil samples. As very limited data could be obtained during 1940 these observations will be carried on during the summer of 1941 also.

It is necessary to point out here that the silt excluders generally serve two purposes :—

- (i) They exclude the coarser grade of the silt found in the river pocket. This is due to the fact that heavier grades of silt are generally found in the lower layers of water. This will be the case if the river water is sufficiently stilled before the tunnels of the excluders are reached. From tables 34 and 36 it will be seen that when there is a flood in the river the silt is so 'churned up' that there is practically no difference in the maximum diameters of the bed silt obtained from the pocket and the canal at R. D. 1,000. This efficiency will be called Qualitative Efficiency, and has been obtained by comparing the maximum diameters of the two bed samples. This is given in Table 36.
- (ii) They exclude a certain volume of the silt in suspension. Efficiency in this case is called Quantitative Efficiency and is obtained by comparing the intensities of coarse and medium silt in the samples collected from the boils of the tunnels and the canal. This is given in Tables 33, 34 and 35.

In calculating this Efficiency the following formula given by Mr. Haigh in P. E. Congress Paper No 211, page 168, 1938, has been used :—

$$E = \frac{\text{Intensity of silt in Flume} - \text{Intensity in Canal}}{\text{Intensity in Flume}} \times 100$$

This has been calculated for coarse and medium silt separately. As the intensity in the flume was not directly observed it has been calculated from the formula—

$$I_f = \frac{Q_c \times I_c + Q_t \times I_t}{Q_f}$$

where Q_f = Discharge in flume $= Q_c + Q_t$.

$=$ Discharge in canal + Discharge through tunnels and the respective intensities.

Coarse silt.—It will be seen from the Table 33 that Efficiency for coarse silt varies from nil to 80 per cent and the variations are apparently erratic. To understand why this is so we shall have to

analyse the limit of experimental error involved in the silt observations.

Limit of Experimental Error.—The quantity of coarse silt obtained from each sample of 5 bottles are put in a silt measuring tube which is capable of reading up to .01 C. C. This apparatus has a constant error of .02 C. C. Hence the smallest quantity that can be read in the tube is .03 C. C. or .042 gms. So that for a sample of 5 bottles, each one litre, the minimum intensity of coarse silt that could be measured would be .0084 gm./litre. If the intensity of silt in the water falls below this point it will be necessary to take more bottles.

It will be seen from Table 33 in which the results of silt sampling for the month of June to September 7th are given that about 50 per cent of the data have to be rejected as the intensity of silt is below this limit. Before the number of bottles of samples could be increased it will have to be determined whether by extending the period of sampling which will be necessary if more bottles are to be collected, the representative character of the samples is not affected. This experiment will be carried out next summer.

In Table 34 are given the data which remain after rejecting those observations given in Table 28 in which the intensity for coarse silt in the canal or the tunnel falls below the above limit .0084 gm/litre.

In Table 34 it will be seen that—

- (1) The Efficiency of the excluder for coarse silt varies from 0.9 to 72 per cent.
- (2) The efficiency is very low for high pond. High pond is accompanied by high river and more silt content. In high river there is more turbulence and hence all the silt is churned up more uniformly leaving practically no difference in silt content between the water which is flowing on the top of the tunnels into the canal and the bottom water which flows into the tunnels. The pond was raised evidently so as to flatten the slope towards the pocket but whether this had any effect on the silt entering the pocket cannot be determined as no observation of silt in the river exists. Comparison with the data for the non-tunnel pocket does not throw much light on this. It appears that for river discharges above one hundred thousand cusecs when the pond was kept high the silt excluders were not of much use. Their efficiencies dropped to very low values.

- (3) Data for days of high pond levels have been rejected from Table 34 and the data for the remaining period tabulated in Table 35 and plotted in Figure 46 against the following ratio:—

$$D. R. = \frac{\text{Canal Discharge}}{\text{Tunnel Discharge.}}$$

From this it will be seen that for the days when the effect of high river is not felt the Efficiency for coarse silt increases as the Discharge Ratio decreases. It is not possible from the present data to say up to what value of D. R. the Efficiency increases. A fresh set of observations during next summer will be arranged to settle this point.

Medium Silt.—Similar analyses carried out on the data concerning medium silt show that the values of the Efficiencies here also are very erratic but the method that was adopted in the case of coarse silt does not bring out any order. This may be due to the fundamental difference in the experimental methods employed in analysing the coarse and the medium silt. The coarse components are separated by pouring the sample through the 100 mesh sieve—the amount that is held on the sieve is called coarse. The medium component is separated from the fine by a process of sedimentation from the fluid that passes through the 100 mesh sieve. The results obtained by the process of sedimentation are apparently less reliable than those by the process of sieving.

Recommendation.—It is proposed to carry out the following series of experiments in this connection during the summer of 1941:—

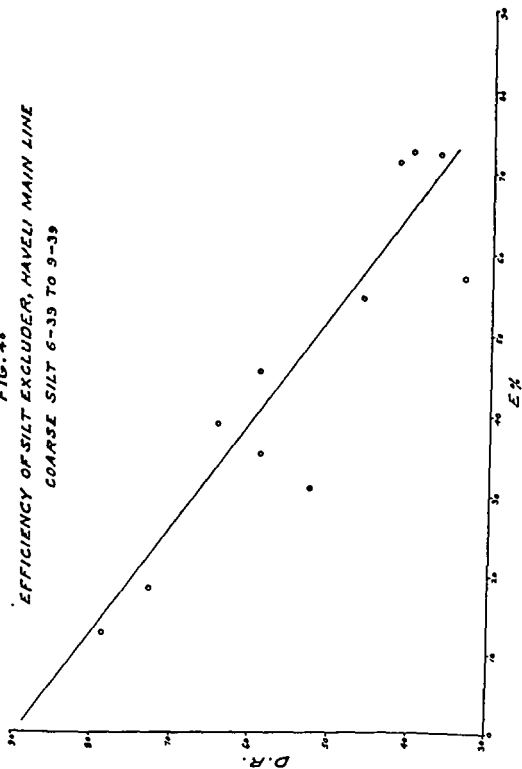
- (1) To find the effect of increasing the number of bottles for each sample on the values of the intensities. This will be done for different ranges of river discharges.
- (2) To find the effect of changing the Discharge Ratio on the Efficiency during flood discharges.
- (3) To find the change in Efficiency for very low values of Discharge Ratios.

Summary.—Working of the Silt excluder in the left pocket of Trimmu Barrage has been analysed for the summer of 1939—

This shows that:—

- (1) So far as the Qualitative Efficiency is concerned, it is not very high. The maximum diameters of the silt in the pocket and in the Haveli Main Line Canal are almost identical.

FIG. 46
 EFFICIENCY OF SILT EXCLUDER, HAVELI MAIN LINE
 COARSE SILT 6-39 TO 9-39



- (2) When the discharge in the river is above 100,000 cusecs the Quantitative Efficiency for coarse silt (as measured by the formula given by Mr. Hugh in his P. D. Congress Paper No. 211), is very low, varying from nil to 8 or 9 per cent.
- (3) For river discharges lower than 100,000 cusecs, the Quantitative Efficiency for coarse silt increases from 12 per cent to 72 per cent as the ratio of discharge between the canal and the tunnels decreases from .78 to .10. This decrease follows a linear law (Fig. 16).
- (4) Efficiencies for medium silt could not be worked out. It appears that the method for analysis of medium silt is defective.

The above deductions are necessarily of very limited application as these have been derived from a set of very limited data. When further data are obtained it may be necessary to revise them.

TABLE 11.

Statement showing m (=mean diameter) of Jhang Branch Upper.

Site	Kharif (26th June, 1938 to 30th June, 1938)	Rabi (30th Nov ember, 1938 to 5th Dec ember 1938)	Kharif (31st May 1939 to 5th June, 1939)	Rabi (27th Nov ember, 1939 to 2nd Dec ember, 1939)	REMARKS
1,000	m 4042	3771 1 70%	3807	3830 2 4%	
5,000	3421	3734	3736 1 10%	3847 1 00%	
10,000	3589	3180	3448	3580	
15,000	3564	3774	3875	3885 1 60%	
20,000	3516	3775 2 8%	3887	3614 1 00%	
25,000	3527	3680	3916	3819 2 10%	
30,000	3652	360 2 10%	3696	3759 2 50%	
35,000	3750	3751	4000 80%	3519	
36,500	3843	3861 2 3%	3544	3735	500' U/S fall
37,500	3847	3728	3555	3540	500' D/S fall
40,000	3775	3768 1 7%	3530	3734 1 6%	
45,000	3670	3770 2 6%	3575 1 10%	3761 1 9%	
50,000	3784	3795	3615	3611 90%	
55,000	3772	3811	4018 2 70%	3587 1 1%	
60,000	3783	3811	3570	3572 2 1%	
65,000	3784	3713	3575 1 7%	3574 1 4%	
68,400	3712	3718 1 1%	3575 1 7%	3578 1 7%	500' U/S fall D/S fall
70,000	3711	3773	3575	3570 1 7%	500' D/S fall D/S fall

TABLE 11—CONTINUED

Site.	Kharif (20th June, 1938, to 30th June, 1938)	Rabi (30th Nov- ember, 1938, to 5th Dec- ember, 1938)	Kharif (1st May, 1939, to 5th June, 1939)	Rabi (27th Nov- ember, 1939, to 2nd Dec- ember, 1939)	REMARKS
70,000	m. 3678	3618	3659	3702	Annoli Distributary
75,000	3714	3660	3418	3400 1.1%	
80,000	3661	3454	3774	3504 80%	
85,000	3598		3766 1.60%	3570 1.1%	
85,000	1388	1707	2023	1896	
1,000					
88,000		..	3785 1.70%	3329	Thatta Raski Distributary
1,000					
90,000	3521	3249	3877	3540 90%	
95,000	3663	3213	3890 1.30%	3592	
100,000	3435	3500	3241	3501 80%	
105,000	3726	3539	3208	3592 1.1%	Boranwala Distributary
110,000	3276	3214	3073	3420	
115,000	3340		3162	3313	
120,000	3119		3405	3185	
125,000	3094	2885	3007	3046	
125,200		2670	2335		
1,000					
130,000	3257	3291	3215	3008	
130,000	1652	1671	1735	1315	
1,000					

TABLE 11—CONCLUDED.

Site.	Kharif (26th June, 1938 to 30th June, 1939)	Rabi (30th Nov ember, 1938, to 5th Dec ember, 1939)	Kharif (31st May, 1939, to 5th June, 1939)	Rabi (27th Nov. ember, 1939, to 2nd Decem- ber, 1939)	REMARKS.
	m.				
248,000	2780	2507	281	2600	Nasrana Distributary
247,500	2952	..	..	..	500 U/S fall R D 248,000
248,500	2912	..	..	..	500' D/S fall R D 248,000
254,000	2617	2711	2827	2851	
255,000	2678	2706	2886	2890	
257,000	0965	1808	1918	1885	Kangra Distributary
1,000					
259,500	2651	2665	2900	2857	500 U/S fall R D 260,000
260,500	3008	2788	2918	3052	
265,000	2754	2628	2808	2898	
270,000	2831	2779		2784	
275,000	2608	2702	2620	2807	
277,000	1265	1691	1730	1464	Madoona Distributary
2,000					
277,000	1676	1642	1753	1899	Wagwala Distributary
1,000					
277,000	2702	2801	2523	2827	500' U/S fall R D 277,500
278,000	2714	2608	2835	2770	500 D/S fall R D 277,500
280,000	2651	2691	2720	2747	
285,000	2808	2754	2787	2870	
290,000	2628	2629	2818	2860	
295,000	2851	2772	2706	2898	
300,000	2836	2845	2871	2908	
305,000	2438	2837	2831	2893	
308,000	2812	..	2822	..	500' U/S Regulator of Branch Reach 5 and Branch Reach Lower.
318,000	1622	1622	2823	2854	Amber Distributary

TABLE 12.

Statement showing mean diameter of Main Line Upper and Lower.

UPPER.

R. D	M mean of the reach	Discharge in cusecs	$S \times 10^3$.	Actual slope	REMARKS.
5,000—40,000 .	4132	10 636	130	·10	
45,000—75,000 .	4308	10,158	146	140	
80 000—115,000 ..	4164	9,864	142	155	
120,000—130,000 .	4116	9,205	143	156	
135 000—140,000 ..	3765	9 247	132	224	

LOWER.

140,500—160,757 .	4002	4,867	160	22	
161,757—182,500	3937	4 847	158	·20	
183,500—200,000 ..	3·02	4,575	154	·19	

TABLE 15.

Statement showing the mean diameter of Rakh Branch.

R D	M' mean dia meter of the stretch	Discharge in cusecs	$S \times 10^3$	Actual slope	REMARKS.
1,000—24,500	3640	1,132	20	200	
25,500—38,000 ..	3670	1,117	20	191	
39,000—49,500	3571	1,083	18	21	
50,500—60,800	3455	1,043	194	193	
61,800—83,600	3250	1,073	180	198	
86,600—113,500	3000	915		165	
114,500—136,500	2892	890	170	195	
137,500—170,000	2693	700	165		
171,000—192,500	2496	600	157	163	
192,500—228,900	2385	572	162	158	
229,900—245,500	2175	399	160	163	
250,000—275,000	2019	373	152	154	
277,000—277,500				166	

TABLE 16.

Mian Ali Branch

R D.	M' mean of stretch	Discharge in cusecs	$S \times 10^3$	Actual slope	REMARKS
1 000—10,000	3015	575	196	194	
15 000—24,385	2851	557	188	205	
30,000—40,000	2786	4 6	192	03	
43,072—65,000	2751	434	192	21	
70 000—75,000	2723	413	192	215	
78,800—100,000	2689	399	192	2 8	

TABLE

Serial No	Canal Site	Name of Channel	PERIOD OBSERVED		Q	A
			From	To		
29	Lower Thelem Canal, Indrawa	Phul Dhar 1900	September 1932	January, 1933	50.45	35.3
30	Ditto	Sukhi Branch 2900	October, 1932	December 1932	304.45	164.2
31	Lower Thelem Canal, Sarghara	N. R. L. D. 7000	February 1933	July, 1933	140.60	50.65
32	Ditto	Mithlak Dhar 4000	Ditto	Ditto	133.10	71.03
33	Ditto	Fatehgarh Dhar 10,200	Ditto	April 1933	44.61	31.64
34	Lower Thelem Canal, G. Sarghara	Northern Branch 102,500	September 1933	November, 1933	74.51	30.05
35	Ditto	Karna Dhar 2100	October 1933	December 1934	443.33	29.02
36	Ditto	Lahar Dhar 1700	Ditto	November 1934	321.45	17.09
37	Upper Bari Doab Canal, Alwal	Alwal Dhar 1,500	February 1934	February 1935	57.14	46.41
38	Lower Bari Doab Canal, K. Sarghara	V. L. R. R. 115,000	March 1935	November 1935	545.02	160.00
39	Ditto	Dhruwala Dhar 18,500	Ditto	January 1936	42.22	29.22
40	Ditto	Jamali Dhar 20,000	Ditto	November 1935	63.41	39.00
41	Ditto	V. L. R. R. 115,000	Ditto	January 1936	55.725	2024.00
42	N. Sarghara	Alwal Dhar, Sarghara 1,500	January 1936	January 1936	17.45	11.51

20—continued

S	R	P	V	A M	V/10 3/4 R 25	Per cent age stock	Period rejected
28	1 73	20 51	1 56	25 62	1 031	1 9	
28	1 71	20 85					
20	2 92	56 25	2 16	20 01	1 130	-6 8	January, 1934, and February, 1935 only
20	3 33	52 72					
17	5 52	100 92	2 52	35 20	11	5 0	February, 1935, and January 1936
18	5 27	105 03					
20	2 81	25 32	1 85	27 29	1 012	-0 8	
24	2 40	32 31					
22	1 80	17 19	1 43	2 29	1 000	0 0	
27	1 67	18 70					
14	4 48	81 64	2 15	27 43	952	2 50	August, 1934
17	4 33	78 43					
20	3 44	60 38	2 12	28 53	994	0 03	Ditto
20	3 58	58 74					
16	3 79	44 81	2 12	27 74	1 004	0 00	Ditto
20	3 35	53 23					
30	1 79	20 20	1 72	35 67	1 089	-4 8	February, March, 1934
34	2 03	25 07					
13	9 37	213 24	2 84	29 64	789	13 0	
12	8 38	210 98					
21	1 66	18 27	1 40	19 87	1 050	-2 6	
24	1 64	18 21					
17	2 25	26 44	1 66	23 74	1 088	-4 8	
26	2 18	27 92					
12	9 46	213 87	2 87	30 34	813	11 3	
12	8 45	213 42					
20	1 22	9 70	1 51	17 77	1 250	-12 4	
26	1 23	11 87					

TABLE 21.

Percentage of shock in some Regime Channels in the Punjab.

Serial No.	Name of the Channel	R. D.	Discharge in cuacs.	Part Per Cent.	Slope Actual/ Cal.	Silt in mm.	Shock percentage.
1	Jhang Branch ..	7,260	2,824	$\frac{144}{149}$	-21'-19"	0.425	+10.1
2	Burala Branch ..	6,000	1,345.96	$\frac{110}{104}$	-24'-18"	0.347	+11.0
3	Lower Gugera Branch ..	11,000	1,829.34	$\frac{120}{126}$	-22'-26"	0.354	-5.8
4	Ditto ..	250,100	1,085.12	$\frac{75}{75}$	-175'-164"	0.284	-6.9
5	Ditto ..	272,500	810.41	$\frac{50}{58}$	-200'-167"	0.267	+5.6
6	Mian Ali Branch ..	88,000	867.70	$\frac{35}{54}$	-231'-239"	0.287	-0.6
7	Shah Kot Distributary ..	12,000	162.20	$\frac{36}{35}$	-123'-123"	0.235	-1.6
8	Hafizabad Distributary	8,000	22.50	$\frac{18}{11}$	35'-35"	0.265	-1.6
9	Khurrianwala Distributary.	8,000	236.04	$\frac{45}{45}$	-122'-127"	0.283	-6.3
10	Rakh Branch ..	218,500	374.38	$\frac{47}{44}$	-141'-175"	0.280	-4.6
11	Lakhuana Distributary	12,000	80.68	$\frac{27}{31}$	-233'-270"	0.247	-3.9
12	Udhoki Distributary ..	2,400	40.31	$\frac{18}{18}$	-27'-30"	0.261	-4.1

TABLE 22.

Observation of water-levels in pipes on 8th January, 1940.

Number of pipe	D LINE	E LINE	F LINE
	R L. of water in pipes	R L. of water in pipes	R L. of water in pipes
1	681 36	680 91	680 33
2	681 48	680 96	680 59
3	681 55	681 02	680 62
4	681 56	681 05	680 66
5	681 77	681 08	680 66
6	681 93	681 78	680 74
7	681 91	681 47	683 54
C G	681 19	680 95	680 85
8	681 27	681 86	681 12
9	R L. not taken	681 25	681 28
10	681 70	681 25	680 76
11	681 66	681 31	680 81
12	681 85	681 39	680 88
13	681 91	681 55	680 95
14	682 07	681 57	681 02
15	682 19	681 56	681 08
16	682 16	681 67	681 08
17	682 17	681 73	681 11
18	682 16	681 68	681 09
19	682 15	681 67	681 08
D G	681 66	681 19	680 76
20	682 21	681 60	681 08
21	682 27	681 70	681 13
22	682 22	681 71	681 15
23	682 11	681 74	681 19
24	682 30	681 97	681 23
25	682 30	682 26	681 29

The fresh supply passed about 7 a. m. at Sagar Head in Upper Gugera Branch on 8th January, 1940, and at Ajmanwala at 1 p. m. after a closure from 15th December 1939

N.B.—Observations were taken before the water passed.

TABLE 28.

Statement showing comparative results of Bottle Sampler and Binkly's Sampler taken from R. D. 143,000 = Main Line Lower, Sagar.

Date	Soundings	Point of Sampling	Temperature of water	1 FT			11 FT			111 FT			REMARKS
				BINKLY'S SAMPLER	BINKLY'S SAMPLER	BOTTLE SAMPLER	BINKLY'S SAMPLER	BOTTLE SAMPLER	BINKLY'S SAMPLER	BOTTLE SAMPLER	BINKLY'S SAMPLER		
				Wt in Gms. per litre	Wt in Gms. per litre	Wt in Gms. per litre	Wt in Gms. per litre	Wt in Gms. per litre	Wt in Gms. per litre	Wt in Gms. per litre	Wt in Gms. per litre		
10th Aug. 1910	85	1 D	21.2°	014	014	012	009	009	009	014	014	Silt in Gms. per litre	Error of measurement may be set at $\pm 1/2$ per cent so that in a quantity of 1 c. c. of silt an error of $\pm .05$ c. c. which is equivalent to ± 15 milligram may be assumed
20th August, 1910	8	2 D	21.2	016	014	016	014	014	014	014	016	016	Silt in Gms. per litre
21st Aug. 1910	85	3 D	23.8°	019	011	014	014	014	014	014	014	014	Silt in Gms. per litre
22nd Aug. 1910	44	1 D	23.6°	01	019	031	021	021	021	021	010	010	Silt in Gms. per litre
Ditto	44	5 D	27.6°	023	016	02	026	026	026	026	028	028	Silt in Gms. per litre
23rd Aug. 1910	85	0 D	22.6°	078	071	078	019	012	012	038	038	038	Silt in Gms. per litre
Ditto	84	7 D	27.0°	075	010	040	012	019	019	050	050	050	Silt in Gms. per litre
24th August 1910	84	8 D	23.8°	091	107	094	094	070	070	070	105	105	Silt in Gms. per litre
25th August, 1910	85	0 D	23.4°	091	075	091	091	091	091	091	272	272	Silt in Gms. per litre

Error of measurement may be set at ± 5 per cent so that in a quantity of 1 c. c. of silt an error of ± 0.05 c. c. which is equivalent to ± 15 milligram may be assumed

Date

Number

Point of Sampling

Temperature of water

REMARKS

Silt in Gms. per litre

Silt in Gms. per litre

Silt in Gms. per litre

Silt in Gms. per litre

Silt in Gms. per litre

Silt in Gms. per litre

Silt in Gms. per litre

Silt in Gms. per litre

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Silt in Gms. per litre

Silt in Gms. per litre

Silt in Gms. per litre

Silt in Gms. per litre

Silt in Gms. per litre

Silt in Gms. per litre

Silt in Gms. per litre

Silt in Gms. per litre

Silt in Gms. per litre

TABLE 29.

Statement showing comparative results of Bottle Sampler and Dr. Puri's Sampler taken from Main Line Lower R. D. 143,000—Lower Chenab Canal, Sagor.

Date of observation	Total depth at point of observation	Depth at which sample taken	Temperature of water	I SET				II SET				III SET.				REMARKS
				BOTTLE SAMPLER		DR PURI'S SAMPLER		BOTTLE SAMPLER		DR PURI'S SAMPLER		BOTTLE SAMPLER		DR PURI'S SAMPLER		
				Medi-um	Coar-se	Medi-um	Coar-se	Medi-um	Coar-se	Medi-um	Coar-se	Medi-um	Coar-se	Medi-um	Coar-se	
10th August, 1940	8 4	1 D	24 4°	219	012	169	001	168	014	156	001	210	012	161	001	Silt in Gms per litre
20th August 1940	8 5	2 D	24 1°	238	019	153	011	202	013	174	001	224	014	171	001	Silt in Gms per litre
21st August, 1940	8 5	3 D	23 6°	317	028	218	018	285	023	204	016	271	026	231	016	Silt in Gms per litre
Ditto	8 5	4 D	24 0°	338	030	230	029	313	028	116	029	327	028	329	031	Silt in Gms per litre
22nd August, 1940	8 4	5 D	23 6°	329	033	340	021	327	028	277	021	320	026	301	024	Silt in Gms per litre
23rd August, 1940	8 4	6 D	22 6°	340	042	288	031	350	042	331	039	378	035	327	043	Silt in Gms per litre
Ditto	8 4	7 D	22 8°	350	063	363	080	364	077	288	047	392	031	303	043	Silt in Gms per litre
24th August, 1940	8 4	8 D	23 1°	294	063	303	054	336	038	264	019	301	119	272	051	Silt in Gms per litre
25th August, 1940	8 5	9 D	23 3°	452	173	333	113	424	140	385	093	406	147	373	101	Silt in Gms per litre

Date.			River Discharge. Upstream.	Pond Level. 480+	UPSTREAM DISCHARGE		Canal Discharge.	Tunnel discharge.
					Non-Tunnel Pocket.	Tunnel Pocket.		
June 1939—								
13th	..	..	103,993	9'00	8,930	9,015	3,792	5,223
14th	..	..	115,027	9'00	8,993	8,605	3,792	4,813
15th	..	..	121,315	9'00	8,091	8,627	3,792	4,835
16th	..	..	116,504	9'00	8,318	9,278	3,792	5,486
17th	..	..	106,693	9'00	8,318	9,278	3,792	5,486
18th	..	..	106,432	9'00	8,993	9,717	3,792	5,925
19th	..	..	101,312	9'10	9,801	10,255	3,792	6,463
20th	..	..	100,914	9'50	10,740	10,872	3,792	7,080
21st	..	..	102,936	10'00	10,882	10,725	3,792	6,933
22nd	..	..	110,447	10'00	10,573	10,526	3,792	6,734
23rd	..	..	115,336	10'00	7,415	9,915	3,498	6,417
24th	..	..	123,202	10'00	7,037	9,588	3,498	6,090
25th	..	..	123,221	10'50	8,517	10,813	3,498	7,315
26th	..	..	135,876	10'50	8,517	10,318	3,003	7,315
27th	..	..	110,369	10'00	8,104	10,731	3,003	7,728
28th	..	..	115,004	9'00	6,898	8,928	3,003	5,925
29th	..	..	96,172	8'00	4,989	7,288	3,003	4,285
30th	..	..	94,522	8'00	6,558	9,561	3,003	6,558
July 1939—								
1st	..	..	88,081	8'00	7,525	10,528	3,003	7,525
2nd	..	..	89,083	8'00	7,221	10,224	3,003	7,221
3rd	..	..	96,984	8'00	5,919	9,736	3,003	6,733
4th	..	..	99,634	8'00	5,844	9,651	3,003	6,644
5th	..	..	91,356	8'00	7,061	10,663	3,003	7,660
6th	..	..	78,095	8'00	7,249	11,249	3,003	8,246
7th	..	..	70,242	8'00	7,936	12,031	3,003	9,028
8th	..	..	66,452	8'00	3,741	9,436	3,003	6,433
9th	..	..	62,733	8'00	4,502	9,536	3,003	6,533
10th	..	..	79,378	8'00	3,813	8,574	3,003	5,571

COARSE SILT			MEDIUM SILT			NON TUNNEL POCKET		Canal Discharge/ Tunnel Discharge	E %	
Tunnel Pocket	Tunnel	Canal	Tunnel Pocket	Tunnel	Canal	Coarse,	Medium		Coarse.	Medium.
0085	0022	0033	0812	4130	3374	1025	5050	726	18 3	11.5
0117	0161	0061	1148	1291	0980	0959	2471	788	47 9	14 6
0235	0059	0000	2007	2961	1927	0020	4109	784	12 8	23 1
0286	0050	0051	1061	1680	1633	0910	2100	691	72 6	1.7
0160	0231	0001	2009	3388	2021	0630	4431	691	62 4	28 6
0146	0180	0089	1212	1302	0961	0581	1842	640	39 0	20 7
0188	0038	0103	2349	2961	1307	0490	1932	587	45 2	41 4
0008	0098	0042	0800	0819	0065	0371	0679	536	46 2	4 4
0500	0030	0462	0960	1100	0660	0161	1309	547	8 9	30 5
0113	0119	0103	0082	0910	0499	0189	0939	563	8 9	34 5
0042	0042	0042	0874	1001	0513	0043	0840	540	0	41 3
0116	0119	0112	0933	1100	0607	0140	1309	574	3 5	34 9
0042	0042	0042	0419	0441	0373	0110	0858	478	0	11 0
0042	0040	0042	0117	0119	0112	0140	0368	411	0	4 3
0061	0063	0056	1522	1841	0000	0200	2471	389	8 2	54 0
0003	0091	0037	0910	1141	0453	0031	0861	507	49 3	50 2
0130	0189	0001	2168	3171	0737	0399	4501	701	61 4	66 0
0046	0008	0112	0004	2240	1647	0511	3250	458	54 5	19 8
0009	0012	0154	2210	2000	1433	1491	3710	399	02 5	35 2
0040	0441	0098	1904	2100	1433	0840	0030	416	71 2	24 7
0251	0060	0187	1500	1750	1167	0441	1680	446	00 5	25 7
0218	0059	0106	1433	1701	0840	0301	2471	452	42 2	41 4
0153	0186	0042	1103	1308	0453	0182	1061	392	72 6	58 9
0332	0400	0092	1482	1790	0635	0028	1930	364	72 3	57 2
0094	00350	0126	1221	1470	0401	0032	0900	333	57 1	61 4
0056	00063	0041	0342	0371	0280	0117	0770	467	26 8	18 1
0096	0112	0061	0357	0420	0219	0119	0382	460	36 5	38 7
0047	0061	0020	0881	0910	0826	0009	1491	539	57 5	6 2

TABLE

Date.	River Discharge Upstream	Pond Level 480+	UPSTREAM DISCHARGE		Canal Discharge.	Tunnel Discharge.
			Non-Tunnel Pocket	Tunnel Pocket		
August 1839—concl'd—						
8th	8 00	4 642	4,499	Closed.	4 470
9th	8 00	5,876	5 684	Do	5 684
10th	8 00	5,949	5 755	Do	5 755
11th	83,146	5,949	5 755	Do	5 755
12th	57,246	5 449	5,755	Do	5 755
13th	54,144	8 00	6 021	Do	5 921
14th	61,352	8 00	6,020	1 250	Closed
15th	60 621	8 00	6,021	9 327	Do
16th	65,306	8 00	6 021	9,327	Do
17th	73,703	8 50	7,659	10 912	3,503
18th	167 307	10 70	5,254	5 082	..
19th	127,594	10 70	6 231	6 025	..
20th	105 860	10 70	6 887	6 662	..
21st	81,124	11 00	9 519	8 319	..
22nd	75,390	11 00	9 872	8 593	..
23rd	84,896	11 00	5 996	6 012	..
24th	79 637	11 00	6 036	6 033	..
25th	68 232	9 50	5 360	5 375	..
26th	85 592	11 25	6 388	7 406	1,000
27th	74 756	11 50	6 564	8 591	2,000
28th	82 646	10 00	5 610	7,656	2,000
29th	92 565	7 00	4 002	6 063	2,000
30th	86 171	7 00	5 076	7 729	2,500
31st	77 145	7 00	5 912	8 051	2,500
September 1839—						
1st	70 342	7 00	5 992	8 618	3 0 5
2nd	74 840	7 50	6 361	9 464	3 503
3rd	50 297	7 50	6 716	9 991	3 700
4th	52 960	8 00	7 552	10 774	3,700
5th	53 957	8 00	7,492	10 718	3,700
6th	41,469	8 50	8 626	10 594	3 700

COARSE SILT.			MEDIUM SILT.			NON TUNNEL POCKET.		Canal Discharge/ Tunnel Discharge	E %	
Tunnel Pocket	Tunnel	Coarse	Tunnel Pocket	Tunnel	Coarse	Coarse	Medium		Coars.	Medium
.	0035	Closed	.	0245	Closed	0175	0420		Closed	Closed
.	0035	Do		0791	Do	0058	1729	..	Do	Do
	0028	Do		0280	Do	0037	0322	.	Do.	Do
0012	0012	Do	0518	0318	Do	0105	1309	0	Do	Do
0070	0070	Do	0420	0420	Do	0084	0726	0	Do	Do
0042	0042	Do	0161	0161	Do	0070	0378	0	Do	Do
0123	0070	0371	1583	1491	2009	0046	1660	215	20 16	26 9
0070	0084	0048	0499	0630	0280	0093	0819	601	31 4	43 9
0085	0094	0070	0696	0700	0686	0175	1771	601	17 7	1 3
0040	0046	0023	0238	0182	0420	0028	1303	473	30 0	62 8
0119	0119	Closed	0770	0770	Closed	0210	0931	0	Closed	Closed
0070	0070	Do	0313	0313	Do	0070	0513	0	Do	Do
0046	0046	Do	0360	0360	Do	0049	0630	0	Do	Do
0049	0049	Do	0210	0210	Do	0037	0280	0	Do	Do
0037	0037	Do	0154	0154	Do	0027	0072	0	Do	Do
0024	0024	Do	0175	0175	Do	0030	0154	0	Do	Do
0014	0014	Do	0037	0037	Do	0046	0081	0	Do	Do
0002	0002	Do	0112	0112	Do	0004	0518	0	Do	Do
0005	0005	0003	0014	0014	0014	0005	0014	156	40 0	0
0002	0002	0001	0005	0006	0002	0002	0009	303	50 0	60 0
0017	0021	0006	0005	0069	0014	0019	0069	354	64 7	74 6
0073	0094	0079	2270	2639	1521	0166	2331	492	60 3	33 0
0077	0093	0042	0447	0489	0359	0081	0886	478	45 5	19 7
0236	0322	0046	1925	2310	1069	0103	3666	450	80 5	44 5
0042	0037	0031	0479	0515	0412	0035	0210	535	21 4	14 0
0097	0117	0063	1769	2189	1055	0166	2429	588	35 1	40 4
0041	0049	0078	0417	0536	0295	0105	0746	588	31 7	31 0
0100	0116	0069	0857	0792	0980	0140	1257	523	31 0	14 4
0031	0035	0023	0190	0245	0085	0058	0256	527	25 8	53 3
0032	0046	0007	0191	0257	0070	0070	0378	542	78 1	63 4

TABLE

Date	River- Discharge Upstream	Pond Level 480+	UPSTREAM DISCHARGE		Canal Discharge	Tunnel Discharge
			Non-Tunnel Pocket	Tunnel Pocket		
August 1939—concl'd—						
8th . . .		8 00	4 612	4 499	Closed.	4 479
9th . . .		8 00	5 876	5 684	Do	5 664
10th . . .		8 00	5,949	5 755	Do	5 735
11th . . .	83,146	8 00	5,949	5 755	Do	5 735
12th . . .	57,246	8 00	5 449	5 755	Do	5 735
13th . . .	54 144	8 00	6 021	5 824	Do	5 804
14th . . .	61 352	8 00	6 020	7 074	1 250	Closed
15th . . .	60 621	8 00	6 021	9 327	3 503	Do
16th . . .	65 306	8 00	6 021	9 327	3 503	Do
17th . . .	73 703	8 50	7 659	10 912	3 503	7 400
18th . . .	167 307	10 70	5,254	5 082		5 062
19th . . .	127,594	10 70	6 231	6 025	..	6 005
20th . . .	105 860	10 70	6 887	6 692		6 672

COARSE SILT			MEDIUM SILT.			NON TUNNEL POCKET.		Canal Discharge/ Tunnel Discharge	E %	
Tunnel Pocket	Tunnel	Coarse	Tunnel Pocket	Tunnel	Coarse	Coarse	Medium		Coarse	Medium
.	0035	Closed	.	0245	Closed	0175	0420	.	Closed	Closed.
.	0035	Do	.	0701	Do	0038	1729	.	Do	Do
.	0028	Do	.	0250	Do.	0037	0322	.	Do	Do
0012	0012	Do	0518	0518	Do	0105	1309	0	Do	Do
0070	0070	Do	0120	0420	Do	0081	0726	0	Do	Do
0042	0042	Do	0161	0161	Do	0070	0378	0	Do	Do
0123	0070	0371	1553	1491	2009	0046	1080	215	-20 16	-26 9
0070	0084	0048	0199	0630	0250	0093	0819	601	31 4	43 9
0065	0091	0070	0096	0700	0086	0175	1771	601	17 7	1 3
0040	0016	0023	0258	0182	04 0	0028	1303	473	30 0	-62 8
0119	0119	Closed	0770	0770	Closed	0210	0931	0	Closed	Closed
0070	0070	Do	0513	0513	Do	0070	0513	0	Do	Do
0046	0046	Do	0560	0560	Do	0049	0630	0	Do	Do
0049	0049	Do	0210	0210	Do	0037	0280	0	Do	Do
0037	0037	Do	0154	0154	Do.	0027	0072	0	Do	Do
0024	0024	Do	0175	0175	Do	0030	0154	0	Do	Do
0014	0014	Do	0037	0037	Do	0046	0081	0	Do	Do
0002	0002	Do	0112	0112	Do	0004	0518	0	Do	Do.
0005	0005	0003	0014	0014	0014	0005	0014	156	40 0	0
0002	0002	0001	0005	0006	0002	0002	0009	303	50 0	60 0
0017	0071	0006	0005	0069	0014	0019	0069	354	04 7	74 6
0073	0094	0029	2270	2639	1521	0166	2331	492	60 3	33 0
0077	0093	0042	0447	0489	0359	0081	0886	478	45 5	19 7
0236	0392	0046	1925	2310	1069	0103	3666	450	80 5	44 5
0042	0037	0051	0479	0515	0412	0035	0210	535	-21 4	14 0
0097	0117	0063	1769	2189	1055	0166	2429	588	35 1	40 4
0041	0049	0078	0447	0536	0295	0105	0746	588	31 7	34 0
0100	0116	0069	0857	0792	0980	0140	1257	523	31 0	-14 4
0031	0035	0023	0190	0245	0085	0058	0256	527	25 8	55 3
0032	0046	0007	0191	0257	0070	0070	0378	542	78 1	63 4

Date.	River Discharge Upstream.	Pond Level. 480+	UPSTREAM DISCHARGE.		Canal Discharge	Tunnel Discharge
			Non tunnel Pocket.	Tunnel Pocket.		
June, 1939—						
13th ..	103,993	9 00	8,930	9,015	3,792	5,222
15th ..	121,315	9 00	8,091	8,627	3,792	4,835
18th ..	106,432	9 00	8,993	9,717	3,792	5,925
19th ..	101,312	9 10	9,801	10,253	3,792	6,461
21st .	102,936	10 00	10,882	10,725	3,792	6,933
22nd .	110,447	10 00	10,543	10,526	3,792	6,734
24th .	123,202	10 00	7,037	9,588	3,498	6,090
30th ..	94,552	8 00	6,558	9,561	3,003	6,558
July, 1939—						
1st .	88,081	8 00	7,525	10,528	3,003	7,525
2nd ..	89,083	8 00	7,221	10,224	3,003	7,221
3rd ..	96,984	8 00	9,919	9,736	3,003	6,733
4th ..	99,634	8 00	5,844	9,651	3,003	6,648
6th ..	79,095	8 00	7,249	11,249	3,003	8,246
7th ..	70,242	8 00	7,036	12,031	3,003	9,028
18th ..	159,220	10 50	7,222	9,239	3,533	5,705
19th ..	161,711	10 50	7,680	10,058	2,737	7,343
24th .	145,929	10 70	5,254	6,800	Closed	6,800
25th ..	168,489	10 70	4,038	7,526	Do	7,526
26th ..	147,223	10 70	4,781	10,943	Do	10,943
27th ..	203,784	10 30	6,334	6,483	Do	6,483
28th ..	184,859	10 70	7,082	7,219	Do	7,219
29th ..	153,692	10 70	7,593	7,716	Do	7,716
30th ..	135,501	10 70	7,660	7,830	Do	7,830
31st ..	115,995	10 70	8,382	8,579	Do	8,579

CLASS 17.			METHOD 5 17.			NEW TUNNEL PROJECT.		Canal Inlet size/Tunnel Inlet charge.	E. %	
Tunnel Inlet.	Tunnel	Flow	Tunnel Inlet	Tunnel.	Coarse.	Coarse.	Med. 17.		Coarse.	Medium.
0028	0022	0041	0012	0030	0074	0025	0035	720	18.3	11.5
0030	0034	0045	0037	0061	0027	0020	0060	784	12.5	23.1
0034	0032	0044	0012	0072	0041	0041	0042	600	39.0	20.7
0038	0038	0043	0040	0041	0047	0040	0032	587	45.2	40.4
0047	0032	0042	0040	0020	0057	0061	0040	547	8.9	30.5
0048	0034	0041	0042	0040	0040	0040	0040	533	8.9	34.5
0049	0040	0042	0043	0040	0047	0040	0040	571	3.5	31.9
0054	0048	0042	0044	0040	0047	0041	0040	478	54.5	19.8
0055	0021	0044	0040	0020	0073	0040	0040	370	72.5	35.2
0040	0041	0048	0040	0040	0043	0040	0040	416	71.2	21.7
0051	0040	0048	0040	0040	0067	0040	0040	446	25.5	25.7
0048	0040	0047	0043	0040	0040	0040	0041	452	42.2	41.4
0032	0040	0042	0042	0040	0045	0048	0032	361	72.3	57.2
0044	0040	0043	0041	0040	0041	0042	0040	331	57.1	61.4
0042	0045	0040	0045	0045	0040	0040	0045	619	9	14.8
0045	0040	0047	0040	0040	0040	0040	0040	421	7.0	0
0048	0048	0040	0040	0040	0040	0040	0040		Closed	Closed
0061	0061	Do	0072	0072	Do	0060	0071		Do	Do
0061	0061	Do	0071	0071	Do	0082	0071		Do	Do
0059	0059	Do	0060	0060	Do	0061	0058		Do	Do
0069	0069	Do	0060	0060	Do	0062	0062		Do	Do
0066	0066	Do	0060	0060	Do	0060	0060		Do	Do
0042	0042	Do	0060	0060	Do	0060	0060		Do	Do
0064	0064	Do	0060	0060	Do	0062	0060		Do	Do

TABLE

Date	River Discharge Upstream	Pond Level 480+	UPSTREAM DISCHARGE		Canal Discharge	Tunnel Discharge
			Non Tunnel Pocket	Tunnel Pocket		
August, 1939—						
1st		10 70	8 983	8 478	Closed	8 478
2nd		10 70	9 144	9 359	Do	9 359
3rd		10 70	9 053	9 266	Do	9 266
4th		10 70	9 144	9 359	Do	9 359
5th		10 60	10 099	10 336	Do	10 336
6th		9 00	7 500	7 717	Do	7 717
7th		8 00	5 566	5 488	Do	5 488
8th		8 00	4 642	4 490	D	4 490
9th		8 00	5 876	5 684	Do	5 684
10th		8 00	5 949	5 750	Do	5 750
11th	83 146	8 00	5 949	5 755	Do	5 755
12th	57 946	8 00	5 449	5 700	Do	5 700
13th	54 144	8 00	6 071	5 824	D	5 824
14th	61 352	8 00	6 070	7 074	1,200	7 074
15th	167 307	10 70	5 254	5 082		5 082
16th	127 594	10 70	6 231	6 070		6 070
20th	100 860	10 70	6 887	6 662		6 662
21st	81 124	11 00	9 519	8 349		8 349
22nd	70 390	11 00	9 871	8 593		8 593
23rd	84 866	11 00	5 996	6 012		6 012
24th	79 637	11 00	6 076	6 053		6 053
25th	68,300	9 50	5 360	5,370		5,370
September, 1939—						
2nd	74 740	7 50	6 364	9 464	3 503	5 961
4th	50,060	8 00	7 552	10 774	3 700	7 074

34—concluded.

COARSE SILT.			MEDIUM SILT.			NON-TUNNEL POCKET.		Canal Discharge. Tunnel Discharge.	E %	
Tunnel Pocket.	Tunnel.	Coarse.	Tunnel Pocket.	Tunnel.	Coarse.	Coarse.	Medium.		Coarse.	Medium.
..	·0037	Closed.	..	·0070	Closed.	·0117	·0329	..	Closed.	Closed.
..	·0028	Do.	..	·0070	Do.	·0140	·0490	..	Do.	Do.
..	·0047	Do.	..	·0516	Do.	·0161	·0364	..	Do.	Do.
..	·0021	Do.	..	·0035	Do.	·0021	·0042	..	Do.	Do.
..	·0042	Do.	..	·0280	Do.	·0012	·0511	..	Do.	Do.
..	·0028	Do.	..	·0189	Do.	·0042	·0378	..	Do.	Do.
..	·0014	Do.	..	·1750	Do.	·0161	·3080	..	Do.	Do.
..	·0035	Do.	..	·0245	Do.	·0175	·0420	..	Do.	Do.
..	·0035	Do.	..	·0791	Do.	·0058	·1729	..	Do.	Do.
..	·0028	Do.	..	0280	Do.	·0037	·0322	..	Do.	Do.
·0012	·0012	Do.	·0518	0518	Do.	0105	·1309	0	Do.	Do.
·0070	·0070	Do.	·0420	·0420	Do.	0084	·0726	0	Do.	Do.
·0042	·0042	Do.	·0161	·0161	Do.	·0070	·0378	0	Do.	Do.
·0123	·0070	·0371	·1583	·1491	·2009	·0046	·1680	·215	20·16	26·9
·0119	·0119	Closed.	·0770	0770	Closed.	·0210	·0931	0	Closed	Closed.
·0070	·0070	Do.	·0513	·0513	Do.	0070	0513	0	Do.	Do.
·0046	·0046	Do.	·0560	·0560	Do.	0049	·0630	0	Do.	Do.
·0049	·0049	Do.	0210	0210	Do.	·0037	·0280	0	Do.	Do.
·0037	·0037	Do.	·0154	·0154	Do.	·0037	·0072	0	Do.	Do.
·0024	·0024	Do.	·0175	·0175	Do.	·0030	·0154	0	Do.	Do.
·0014	·0014	Do.	·0037	·0037	Do.	0046	·0081	0	Do.	Do.
·0002	·0002	Do.	·0112	0112	Do.	·0004	·0518	0	Do.	Do.
·0097	·0117	·0063	·1769	·2189	·1055	0166	·2429	·588	35·1	4·4
·0100	·0116	·0069	·0857	·0792	·0980	·0140	·1257	·523	31·0	—11·4

TABLE 36.

AVERAGE DIAMETER ($m \times 10^2$ in mm) OF BED SILT SAMPLES COLLECTED
FROM HAVELI MAIN LINE DURING 1939.

Sta. c.	June H. M. Line.	July H. M. Line	September H. M. Line	REMARKS.
1st	Feet 22.52	Feet. ..	Feet. ..	Samples from the bed of the left pocket were collected on very few occasions in 1940—
2nd	26.32	..	..
3rd	..	..	..
4th	..	23.37	..	13th May, 1940 .. 26.86 17th May, 1940 .. 27.39
5th	..	..	..
6th	25.63	..	25.81	
7th	.	21.84	.	
8th	..	.	..
9th	25.55	..	..
10th		..	..
11th	..	26.00	..	
12th	..	..	..
13th	27.58	..		
14th	..	26.60	.	
15th		..	..
16th	24.40	.	..	
17th	.			
18th	..			
19th		23.74	20.74	
20th	26.19	..		
21st				
22nd	..	24.73		
23rd			24.84	
24th		.		
25th				
26th	.		28.00	
27th	2.02	.		
28th	.			
29th			.	
30th	..	..	28.08	
31st	..	..	..

NANUNA JHANG BRANCH R. D. 7,260.



Discharge in cusecs	..	2,824
P _{act.}		144
P _{cal.}		149
Slope		
Actual/Calculated	.	21/19
Silt in mm.	.	0 425
Shock%		+10.1



BUCHIANA BURALA BRANCH R D 6,900



Discharge in cuses	1543.99
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P_{act}	110
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P_{cal}	104
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Slope Actual Calculated	24/18
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Silt in mm	0.347
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Shock%	+11.0
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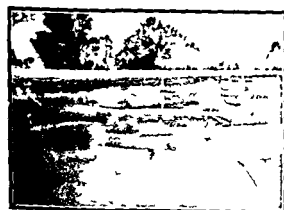
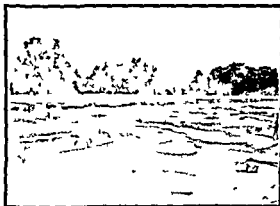
BUCHIANA LOWER GUGERA BRANCH R D 11 000



Discharge in cusecs	1,829 34
P_{act}	120
P_{cal}	126
Slope	
Actual Calculated	22/ 18
Silt in mm	0 354
Shock ^o	+8 8



TARKHANI LOWER GUGERA BRANCH R. D. 259,100.



Discharge in cusecs	1085.52
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$P_{act.}$..	92
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$P_{cal.}$..	92
------------	----	----

Slope	
-------	--

Actual	Calculated	178/ 164
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Silt in mm.	0 284
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Shock%	+6.9
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TARKHANI LOWER GUGERA BRANCH R. D 272,500



Discharge in cusecs

810 91

 P_{act}

80

 P_{cal}

73

Slope

Actual/Calculated

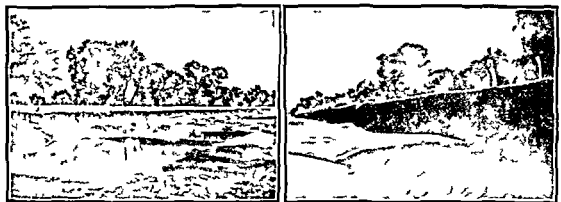
200/ 160

Silt in mm

0 260

Shock %

+8 8



STATISTICAL SECTION.

I—INTRODUCTORY.

The problems facing the irrigation engineer can broadly be divided into the following groups :—

- (a) Problems of production.
- (b) Problems of distribution
- (c) Problems of consumption.

(a) PROBLEMS OF PRODUCTION.

The problems of production can again be divided into two groups :—

- (i) Problems arising in the case, where the supplies are available from surface sources.
- (ii) Problems arising in the case, where the supplies are drawn from sources below the surface of the earth.

(i) *Supplies available from surface sources*—The sources of surface supplies are rain and snow. The rivers are fed by the melting of the snows and by that part of the rainfall which runs off the surface into the rivers or their tributaries. The lakes—natural, or artificial—derive their supplies either from the rainfall which runs off the surrounding country into the depressions formed by the beds of the lakes or from a stream or streams flowing into the lakes. The reservoirs built for storage of rain water can be taken as belonging to a special type of artificial lakes.

The surface supplies of water always include a certain amount of solid matter, loosely included under the general term “silt”

The problems of production from surface sources include those relating to the measurements for volume of water and silt, to the changes in these and in the supply levels, with special reference to the corresponding changes in the factors affecting the supplies, and to the construction and stability of the works required for storing or regulating the supplies.

The investigations carried out during the year in regard to such problems are given below —

- (1) Jaba Failure and After.
- (2) Sloping Toewall and Stability of Kalabagh Weir.
- (3) Lay-out of Pressure Pipes for the Depressed Bays of Islam Weir
- (4) Analysis of Pressure Pipe Observations on the Islam Weir.
- (5) Stability of Bays 5—8 of the Khanki Weir.

(6) Walls or no Walls: Pressure Distributions for Alternative Sections of Chhenanwan Regulator.

(7) Stability of Floor with Pile and Upward Step at Toe.

(ii) *Supplies available from sub-surface sources.*—The sub-soil reservoir is the source of such supplies. It is drawn upon by open wells, or tubewells.

The irrigation schemes mainly dependent on pumping from the sub-soil, so far supply only a very small fraction of the total volume required for irrigation in the Punjab. The Karol Tube-well Project and the Western Jumna Extension Scheme have been taken up as a result of the work of Mr. A. M. R. Montagu. The analysis of the results of basic experiments carried out for him by the Institute was described in the last annual report, and no further investigation has been carried out this year. When the results from field are available for a few years, it will probably be possible to correlate these with the results derived from the theory and the model observations.

(b) PROBLEMS OF DISTRIBUTION.

The problems of distribution may be taken to start when the water passes from the river into the canal. They can be divided into three groups:—

(i) Problems arising from the flow of water and transport of silt in alluvial earthen channels.

(ii) Problems arising from the flow of water over, under or through the works built at different points of the distribution system.

(iii) Problems arising from the flow of water from and into the soil through which the distributing channels are constructed.

(i) *Flow of water and transport of silt in alluvial earthen channels.*—The flow of water in an alluvial channel is to be studied in relation to the transport of silt which is carried or rolled by the water. The width, the depth and the slope of the channel depend on the volume of water carried and on the grade and content of silt. The general problem is to so design the distributing system, that, consistently with the lie of the land, all the channels run without silting or scouring the bed or the sides. There may be seasonal changes, but over a number of years the system should be stable.

A study of channels which have remained stable can lead to the relations which exist between the different observed elements on such channels. These relations can then be used as guides for designing new channels, or for remodelling old ones which are unstable.

The technique of observations gives rise to its own problems. Firstly there are the discharge measurements, in which the volume of water passing a given section of the channel is obtained from observed values of depths and velocities at different verticals of the section. The spacing of these verticals, and the need for selecting the instrument and depth so as to get as accurate an estimate of velocity as possible, require careful thinking. Secondly, we have the problems relating to the sampling and analysis of suspended and bed silts, from which the silt indices of the channel are ultimately derived. At what depth should a sample of water be taken to get the mean silt content for the section? Do different samplers give the same suspended silt content? Are the results obtained from analyses by different instruments or methods in fair agreement? Does the temperature of water affect the result of analysis? These are a few of the questions which need to be answered.

The design of the distribution system also leads to a study of the total volume and of the grade of the silt which it can carry. This, in turn, requires a study of the entry of silt at Headworks.

The subject of design of stable earthen channels has been greatly advanced by Mr. Gerald Lacey, and his theory has formed the subject of several investigations.

The investigations carried out during the year in relation to the problems of silt and flow are:—

- (8) Mean Velocity Point on a vertical.
- (9) Sampler *versus* Sampler (suspended silt).
- (10) Mean Silt Point on a vertical.
- (11) Studies on rolling silt.
- (12) Temperature and silt size.
- (13) Verification of Lacey's General Regime Formula:

$$V = 16R^{2/3}S^{1/3}, \text{ from his own data.}$$

- (14) "Shock" and "Coherence" in Regime Flow.
- (15) Most Efficient Section.
- (16) Khushalani's "Rolling Theory" of Flow.
- (17) Optimum Slopes for Babehali Distributary, Upper Bari Doab Canal.
- (18) Silt and scour on the Main Line, Lower Jhelum Canal.

The first five of these are in the nature of analyses of basic experiments carried out by the Institute in field or in laboratory. The next four deal with some aspects of the theories of stable flow. The last two apply the knowledge gained so far to the analysis of conditions existing on two very different types of channels.

While the subject of lined channels comes more appropriately under the third group of the problems of distribution, as lining is usually adopted to prevent losses into the soil, the two investigations relating to such channels, which were completed this year, dwell more

on the silt-carrying capacity of such channels than on their economical aspect, and may, therefore, be put into the first group.

These are :—

(19) Silt distribution on Bikaner Canal.

(20) Rugosity Coefficients on lined channels, with special reference to the design of channels included in the Lower Chenab Canal Lining Project.

(ii) *Flow of water over, under or through works built on the distribution system.*—The flow of water through, over or under the works—so long as the flow is not through the soil—gives rise, among others, to the problems of what is known as “surface flow”. The works are required either for distribution, e.g., regulators and outlets, or for adjusting the supply levels, e.g., falls, or for carrying and measuring the supplies, e.g., syphons, falls, and meter flumes. The stability of these works, and their utility as measuring devices gives rise to a number of important problems.

The investigations dealing with this class of problems are :—

(21) Design of Glacis Profile, I.

(22) Discharge Coefficient. Degree of submergence and splay.

The first investigation examines the theory of glacis profile as enunciated by Messrs. Montagu and Bose. The second gives the analysis of observations carried out for a number of fall types.

(iii) *Flow of water from the distributing channels into the soil and vice versa.*—If a distributing channel runs through pervious soil, and the level of water in it is higher than in the surrounding country, a certain volume of water may flow through its bottom and sides and join the sub-soil water-table. When the level of water in the channel is lower than in the neighbouring sub-soil, some of this water may flow into the channel through its bed or its banks. The flow into the sub-soil is called “seepage” and that from the sub-soil is “back-seepage”. Alternative terms are “absorption” and “regeneration”.

As seepage means the loss of valuable water and an increase in the capacity of the channel in order to carry water which will be lost en route to the consumer, the irrigation engineer is vitally interested in seepage problems. Firstly there is the question of measuring seepage losses. This requires discharge measurements at the ends of the reach for which the seepage is to be estimated, and the evaluation of any additions from or withdrawal by surface sources, e.g., rainfall inlets, and discharge outlets, respectively. The determination of the number of measurements necessary for an accurate estimate and the selection of right instruments are problems in themselves.

Secondly there are the problems which arise as a consequence of extensive seepage. These include waterlogging of neighbouring strips of land, as shown by a rise in water-table. The analysis of factors responsible for this rise is another problem.

The prevention of seepage gives rise to the third group of seepage problems. The choice of a lining which will be of the greatest utility under a given set of conditions and the estimation of its usefulness in (a) saving water and (b) reducing the rise of watertable belong to this group.

Finally there are the problems connected with the cure of the evil results, if any, of seepage. The rapid removal of water by surface drains is one way of keeping the watertable down, and the construction and maintenance of these drains gives rise to a host of problems. The effect of drainage on land is yet another.

The investigations relating to seepage problems are :—

(23) Seepage losses on Kot Nikka Branch, Lower Chenab Canal.

(24) Proposed Seepage experiments on Dangali Distributary.

(c) PROBLEMS OF CONSUMPTION.

The object of the engineer is to make the most of every drop of water. The application of the canal water to the land by the consumer gives rise to the problems of consumption, which can be classified as below :—

(i) Problems relating to the quality of the land, which is being irrigated or is proposed to be irrigated.

(ii) Problems relating to the utilization of the supplies.

(iii) Problems relating to cropping.

(i) *Problems relating to the quality of the land.*—The deterioration of certain large tracts, following the introduction of irrigation, has shown the need for a survey of the soils in any area proposed to be irrigated, and for an investigation of the reasons for such deterioration in irrigated areas. The physical and chemical properties of the soil, and the movements of water and salts through different layers have been studied by the Institute in detail, and these have been used for explaining the changes in the quality of the land. The problems of Soil Physics, Soil Chemistry and Land Reclamation belong to this group.

The effect of measures adopted to prevent deterioration of land is best gauged by changes in cultivated area. The only investigation under this group which relates to such measures shows the improvement resulting from the introduction of drainage.

The investigations carried out in this group are :—

(25) Relation between conductivity and total salts.

(26) "Specific surface" of soil. Its relation with other soil properties. Is it superior as an index to "clay content"?

(27) Graphical method for finding "specific surface".

(28) Increase in cultivated area through drainage.

The changes in the area affected by salts form the subject of another investigation.

(29) Changes in Thur area in 8 districts of the Punjab.

(ii) *Problems relating to utilization of supplies.*—The economical use of water by the cultivator would bring a greater return to the engineer, as the assessment is on the basis of acreage irrigated and the volumetric system cannot, for certain reasons, be equally successful. The factors which affect the area irrigated are: supply, timely rain, prices, quality of land, etc., and an analysis of the effect of each is of the greatest interest to the Irrigation Department.

No investigation relating to this group was completed in 1940-41.

(iii) *Problems relating to cropping.*—The crops grown in a given irrigated tract depend for their growth on a number of factors. The soil type and supply often determine what crop can be grown profitably. The water requirements of the crops and their yields under varying conditions have to be studied carefully in order to strike a fair balance between the engineer, who is interested in getting the maximum irrigated area for a given volume of water, and the cultivator, who wants the maximum outturn. Experiments for the improvement of land by different systems of cropping also come within this group.

The investigations carried out during the year are:—

(30) Early Closure of Kharif Channels and Rice Cultivation on the Upper Chenab Canal.

(31) Lay-outs for Experimental areas in Thal.

Besides the above investigations, the following which were in the nature of advisory studies were also carried out:—

(32) Failure and Reconstruction of the Tail Fall of Nathaura Escape, Hardoi Branch. (For Chief Engineer, United Provinces).

(33) Approximate formula for finding the Slab Thickness from Bridge and Girder Spans. (For Officer on Special Duty, Communications Board).

(34) Stabilization of Earth Roads. (For Road Research Scheme).

(35) Graphical solution for "Flow point." (For Mr. Hickey, Chief Engineer, United Provinces).

II.—PROBLEMS OF PRODUCTION.

1. Jaba failure and after.

The failure of the Jaba Weir was considered to be due to the fact that piles had been driven almost into the clay sub-strata lying under the weir. This led to a ponding up of the pressure under the floor and an increase in the uplift led to the failure of the work. The theory for the case where the stratum of clay lies under the structure and the downstream pile is not driven into the clay had not been previously worked out. In order to compare the pressures recorded under the Jaba Weir with those which would be theoretically obtained in such a case led to an investigation, from the mathematical point of view, of such pressures.

The theory has been successfully worked out during the year. The calculations are nearly complete. It is proposed to publish the results at a later date.

2. Sloping Toewall and Stability of Kalabagh Weir.

This investigation was initially taken up in July, 1939. At that time there was some doubt if piles could be driven into the bed of the river Indus at Kalabagh, as shingle and other coarse material formed a large proportion of the foundations. Mr. Haigh, Superintending Engineer, 1st Thal Circle, therefore, hit upon the idea of laying a sloping toewall, after removing the bed material. The material could be replaced after the toewall had been built.

The effect of such a toewall on the stability of the weir was required to be worked out, and the Chief Engineer, Construction Administration, referred the matter to the Institute.

It was not known at the time if the laws of flow of water through a shingle stratum are the same as those for its flow through a layer of sand. It was assumed that shingle and sand together formed a homogeneous mixture. This was later found to be at variance with the results from model experiments carried out in the Hydraulic Section.

The difficulties in the way of driving the piles were later found to have been exaggerated and the utility of this investigation was, therefore, more or less a matter of doubt. Mr. Haigh, however, considered that it would be of interest to complete it. The original note sent to him in August, 1939, was, therefore, enlarged and now awaits publication.

It may be added in this connection that the theoretical values for such a case are in good agreement with those obtained from the electrical models. The latter have been described in a paper published in the Proceedings of the Academy of Sciences.

3 & 4. Lay-out of Pressure Pipes for the Depressed Bays of Islam Weir, and Analysis of Pressure Pipe Observations on the Islam Weir.

In 1929, six bays of the Islam weir collapsed suddenly. They were replaced by 11 depressed and gated bays of 29 feet span—the bays 11 to 21 of the present structure.

In December, 1936, pressure pipes were inserted in bays 11, 16 and 21. In 1937 the pressure pipe observations in these and other bays were analysed and some of the bays were found to be unsound. It was recommended at the time that a downstream pile line may be placed in bays 1 to 10 and 22 to 29.

A proposal for putting in the downstream piling in bays 11 to 21 was considered in 1940. This was deferred till the evidence of cavitation below the downstream floor had been collected. It was considered desirable to fit the depressed bays with pressure pipes and to examine the results with a view to ascertaining if the actual pressures indicated any danger. The Superintending Engineer, Nili Bar, was asked to fix the position of these pipes in consultation with the Director, Irrigation Research.

The data for the bays 11, 16 and 21 of the Islam Weir were analysed for four days in April, 1938, when the head on the weir was 17 feet to 18 feet. This showed that at that time there was probably an imperfect contact between the pacca floor and the shingle placed between the caissons in the last 42 feet of the work, but that the bays were otherwise sound. About a quarter of the head was lost at entry of water at the upstream end, possibly due to a silt blanket.

The general principles for layout of a set of pressure points, as enunciated by Khosla in chapter V of "Design of Weirs", C. B. I. Publication No. 12, were examined in the light of later researches. As a result the following rules were framed:—

The pressure pipes should be placed—

- (1) At larger intervals under the horizontal floors than along the vertical cut-offs.
- (2) At points, the percentage residual heads at which are estimated to differ by at least 8 to 10 per cent of the total head.
- (3) More closely near the toe of the work than upstream of the crest.
- (4) At closer vertical intervals at the ends of the work than at the centre, if any pipes are to be placed in the sub-soil.

A layout was suggested for insertion of pressure pipes in bays 11, 16 and 21, as also in bays in which pressure pipes had not been previously fixed. The total number of pipes suggested was 73, of which 9 were already fixed. Sixty-four new pipes were, therefore, to be fixed in addition.

It was recommended that the last 62 feet length of the floor in the depressed bays may be tested for hollows during the next cold weather, provided the analysis of pressure pipe observations in bays 11, 16 and 21 for April, 1938, was confirmed by a similar examination of the subsequent data on record. This examination was carried out in December, 1940.

The analysis revealed that it was necessary to watch the depressed bays, but that there was no need for taking any alarmistic view of the situation. It was recommended that bay 16 should be examined and that pressure pipe data for the pipes proposed to be put in may be accumulated and analysed. The data already examined covered a period of more than two years and the results were in general agreement with those obtained from the earlier examination of the data for April, 1938.

5. Stability of Bays 5—8 of the Khanki Weir.

In order to obtain control of discharge in the left half of the river the Institute had suggested that the gates and shutters in bays 5—8 be raised by two feet, i.e., to a R L of 735 0. The Executive Engineer, Khanki, commenting on this, stated that bays 5, 6 and 7 would not be safe under the extra head. The Institute was asked to examine the Executive Engineer's remarks.

The calculations by the Executive Engineer were examined and it was found that two serious errors largely vitiated his conclusions —

- (i) He had used the submerged density of the load of masonry instead of actual density which was the proper quantity to use
- (ii) In the case of bay 8 the R L of hydraulic gradient line was shown lying below the lowest water level downstream, at the point of the junction of the floor with the upstream face of the toe pile. The reason for this was not clear

All the calculations were, therefore, repeated. It was concluded that bays 5, 6 and 7 would be safe against the extra head, that bay 8 would require extra thickening in the last 50 feet, and that there would be no danger of piping due to the increased head, provided the inverted filter area in bays 6 and 7 was functioning properly.

6. Walls or no Walls Pressure Distributions for Alternative Sections of Chhenanwan Regulator.

It was proposed by the Executive Engineer, Khanki Division, that a heading up of 1 0 foot be permitted. The regulator, situated at R D 40,000 of Lower C, had previously allowed at this work and in order to judge the likely effect of heading up on the stability of the work he asked the percentage residual heads to be worked out for the two following alternative profiles.—

- (a) masonry slab, 30 feet in length, 3 feet thick for the first 20 feet and 2 feet thick for the remaining length; with cut-off walls at heel and toe, the walls to be 4 feet thick each and with bottom level 8 feet below the top level of the slab

- (b) Masonry slab as before, but without cut-off walls.

The values for percentage residual head were worked out for both the cases at various points under the profiles. It was found that an omission of toewalls would increase the uplifts in the upper half of the slab and reduce them in the lower half, the changes being most noticeable at the points at the joins of the cut-off walls with the slab. The omission of the cut-off walls, would, however, give a higher exit gradient. It, therefore, appeared preferable to keep both the toewalls, if possible, or at least the downstream cut-off; especially as the slab was known to rest on fine sand.

7. Stability of Floor with Pile and Upward Step at Toe.

The Superintending Engineer, Upper Jhelum Canal (Mr. F. F. Haigh), suggested that it would be useful if a Table similar to Table VII-3 of the C. B. I. Publication No. 12 could be prepared for the case where the underside of the floor was below the downstream bed level.

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A note was prepared giving the theory, the required tables, together with 8 plates of diagrams corresponding to plates VII-1, VII-2-A, VII-2-B (2 plates), VII-3-A, VII-3-B, VII-3-C and VII-4 of the "Design of Weirs."

III.—PROBLEMS OF DISTRIBUTION.

8.—Mean Velocity Point on a Vertical.

From the observed velocities at 0, .1, .2,.... and .9 of depth on symmetrically placed verticals the ratio of the depth of the mean velocity point to the total depth at the vertical was calculated, by plotting the velocities against depths, drawing a smooth curve through the plotted points, extrapolating for the bed velocity, and calculating the mean velocity from the curve readings.

Twenty to twentyfive sets of observations were taken on each of the 8 channels and the values of the ratio "M. V. point depth/vertical depth" were worked out. It was found that the ratio was very nearly .6 on the three intermediate verticals and that on the end verticals the ratio was more nearly equal to $2/3$. It was also found that if the ratio was taken as 0.6 on the end verticals the difference in velocity for the vertical would be nearly .1 foot sec. The discharge would, therefore, be exaggerated by about $1/5$ to $1/10$ per cent. It could, therefore, be stated that the existing practice of taking this ratio as equal to .6 gave a close approximation to the actual value of the discharge.

9. Sampler versus Sampler (Suspended Silt).

A series of experiments were carried out at Sagar on the Lower Chenab Canal, in order to examine the agreement between the different types of silt samplers. At each depth on a number of verticals samples were taken with the help of the standard bottle sampler, and the coarse and medium contents compared with those obtained by Binckley, Puri, Uppal, and Jagat Ram samplers. The results have been examined in detail and it was found that except at points near to the bed there was a fair measure of agreement between the different samplers. It is proposed to continue this analysis with data which are being accumulated and to publish the results as a whole. Another experiment was carried out in order to find if the capacity of the different samplers varied at different times. Fifty samples were taken for each of the four samplers, Puri, Uppal, Jagat Ram and Binckley, and their variations about the mean capacity determined. It was found that the Puri and Uppal samplers showed the lowest variation. These, however, have a smaller capacity than the Jagat Ram sampler.

The object of these experiments was to find out if the labour of sampling could be reduced by taking a large volume of water once instead of taking smaller volumes a number of times. As far as the present results go it seems that samplers with smaller volumes gave a more consistent capacity than those with bigger volumes. The investigations are proposed to be extended.

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The mean silt content of a channel has so far been taken as equal to the silt content at .6 depth in the centre of the channel. This value was found as a result of some earlier experiments carried

(b) Masonry slab as before, but without cut-off walls.

The values for percentage residual head were worked out for both the cases at various points under the profiles. It was found that an omission of toewalls would increase the uplifts in the upper half of the slab and reduce them in the lower half, the changes being most noticeable at the points at the joins of the cut-off walls with the slab. The omission of the cut-off walls, would, however, give a higher exit gradient. It, therefore, appeared preferable to keep both the toewalls, if possible, or at least the downstream cut-off; especially as the slab was known to rest on fine sand.

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It has been shown that an approximate formula used by him for the perimeter of a semi-elliptical section in terms of the surface width and the maximum depth can be replaced by a more accurate formula, which leads to a rigorous proof of a result given earlier by Mr. Lacey, that the minimum regime velocity equals .882 feet per second and that this is attained only when the section is a semi-circle. It is also shown that for a semi-elliptical section the wetted perimeter will always exceed

$$\sqrt{2 \pi \cdot \text{Area.}}$$

17. Optimum slopes for Babehali Distributary, Upper Bari Doab Canal.

The Babehali Distributary of the Upper Bari Doab Canal was giving constant trouble on account of silt and it was proposed by the Executive Engineer, Gurdaspur, to shift its head from Main Branch Upper to Kasur Branch Upper. The channel has a discharge of about 60 cusecs and carries very coarse material. He requested that the slopes which should be given to the various reaches to obviate the silting trouble in future may be intimated to him.

Bed silt samples taken at different points of the distributary were analysed, the mean diameters plotted against the R.D.'s, a smooth curve drawn and the values read for each of the ten different reaches for which available discharges were given. The slopes were calculated from the Bose formula

$$S_B \times 10^3 = 2.09 \frac{m^{.86}}{Q^{.21}}$$

These were compared with the slopes calculated from the Lacey Slope formula, but in view of the uncertainty as to the relation between f and m in the latter were not discussed further.

It was recommended that the slopes as calculated be adopted in different reaches, provided the channel could be graded in that manner. If, on the other hand, the slope was to be uniform and equal to the present overall slope then it would be necessary to exclude some of the coarser particles at the head of the channel. It also appeared that there was not enough evidence to show that the shifting of the head would definitely result in the distributary getting its water from a channel with a lower silt intensity or with a finer bed silt than that from which it took off at present.

18. Silt and Scour on the Main Line, Lower Jhelum Canal.

Trouble due to silting was reported on the distributaries of the Lower Jhelum Canal system. The advice of the Institute regarding the regrading of the Main Line above Fakirian, by introduction

of suitable falls, was sought by the Executive Engineer, Rasul. The Northern and Southern Branches were inspected and considerable silt movement was noticed in the Northern Branch up to mile 50.

The object of the investigation was to see if the silting trouble was due to the scouring of the Main Line above Fakirian and if so, whether the channel required regrading.

The silt and scour observations taken at every mile of the Lower Jhelum Canal up to mile 39 were available in the Institute from May, 1935, to December, 1940. These were analysed and it was seen that the canal was in scour throughout the reach, the scour in the head reach being about 6 feet and at the tail about $1\frac{1}{2}$ feet. After April, 1938, there did not appear to be any tendency for the channel to scour or silt, though from May, 1935, to April, 1938, there was some increase in scour in the first four miles.

The levels in December, 1922, and December, 1940, showed that the average bed slope between these two dates did not materially change.

The samples taken from the canal in October, 1940, showed that there was very little silt deposit on the bed and that the samples contained more or less coarse bed soil.

It was concluded that the trouble in the distributaries could not be due to the progressive scouring in the canal, which was running to a steady slope of about .13 per thousand since 1922. The bed silt diameter of the river samples also showed that this was the slope which may be expected from the Bose formula. It appeared, therefore, that the channel need not be re-designed to a different slope.

19. Silt Distribution on Bikaner Canal.

While designing the lined section of Rakh Branch, the Executive Engineer (Mr. T. Blench) was called upon to adjust the silt distribution between the branch and its offtakes. There being no data available for silt distribution in a lined channel the present investigation was carried out at his request at R.D. 36,000 of Bikaner Canal; this point is about 2 miles below R. D. 25,000, where the lining on this canal starts.

The coarse and medium silt contents in suspension were obtained at different points of the cross section. It was found that these increased with depth, but that there was little change with distance from the bank. These samples were also graded, but it was found that the silt grade did not appreciably change either with depth or with distance from the bank.

20. Rugosity Coefficients on Lined Channels, with special reference to the design of Channels included in the Lower Chanab Canal Lining Project.

The values of rugosity on Haveli Main Canal were first calculated by the Officer on Special Duty, Waterlogging Investigation, and the Institute; from the data received from the Executive Engineer, Main Line Division (Mr. C. L. Handa). The mean value of $\cdot 0150$ for Lacey's N , was obtained from the data for May, 1939. In subsequent analyses by the Institute of the data for June and July, 1939 this value rose to nearly $\cdot 0160$.

Subsequently the data for R. D.'s 2,500 and 217,100 of Haveli Main Canal were analysed by the Central Designs Office, and it was concluded that the values of N increased with a diminution in supplies. The Institute was asked to examine all the results and to suggest a suitable value of N for the Lower Chenab Canal Lining Project.

It was pointed out that the analysis by the Central Designs Office was vitiated by the fact that the gauges at R.D. 2,500 and 217,100 were too close to the beginning and end of the lined sections, and were mostly for days of small supplies.

The values for Lacey's, Manning's and Kutter's N 's were calculated and it was recommended that while there was little to choose between the different formulæ the value of Lacey's N equalling $\cdot 0160$ would prove to be the best guide. The corresponding values for Manning's and Kutter's N 's were suggested as $\cdot 0149$ and $\cdot 0117$, respectively. It was also suggested that a discharge site be located on the Haveli Main Line and daily observations taken for a few months, from which the relation between V , R and S should be deduced.

21. Design of Glacis Profile—I.

The shape of the glacis of a weir or a fall has been investigated by Messrs. Montagu and Bose. The results were given in Appendices 6-A and 6-B of "Irrigation Canal Falls", C. B. I. Publication No. 10. Briefly the object was to so design the profile of the glacis that the maximum horizontal acceleration is imparted to the stream leaving the crest. It was assumed that the stream leaving the crest could be treated as a particle having the same velocity as the horizontal mean velocity of the stream and that the glacis had no friction. The solutions obtained by Mr. Montagu and Dr. Bose were, however, different. Further, Dr. Bose, considered his own solution to be only a close approximation to that desired.

The mathematics given by Montagu and Bose was first re-examined in an attempt to reconcile, if possible, the two solutions. This led to a new method of approach, based on the same premises.

The mathematics of Montagu profile was found to be erroneous. It was found that there was an imperfection in the logic, as Montagu

had imparted negative and positive velocities in succession without noting the fact that the glaciis is a reality and not an ideal curve in space.

It also appeared that this profile, apart from its mathematical invalidity gave as high a vertical acceleration to the stream as a horizontal acceleration, and that it may give higher accelerations for initial velocities lower than the one figuring in its equation. The object of reducing the vertical acceleration was not, therefore, fulfilled.

The mathematical derivation of Bose profile was found to be correct. This profile gave a higher horizontal acceleration than Montagu profile for the case examined. It did not, however, reduce the vertical acceleration.

22. Discharge Coefficient, Degree of Submergence and Splay.

Four types of falls were examined in the Hydraulic Section. The first of these was the Montagu type; the other three were types designed by the Central Designs Office. The latter had varying slopes; vertical, 1 in 3, and 1 in 5. A discharge corresponding in the prototype to 1,630 cusecs was run. The upstream splay was 1 in 2 and the downstream splay for each type was varied. The values for the downstream splay were $1/2$, $1/3$ and $1/5$. The discharge coefficients were determined in each case for different degrees of submergence. The analysis of the data led to the following deductions:—

- (i) The degree of submergence has a very significant effect on the co-efficient, which goes down as the degree of submergence increases.
- (ii) The downstream splay also exercises a significant effect on the co-efficient. If the splay be 1 in n , then the co-efficient increases with n .
- (iii) The type of fall influences the co-efficient, but to a much lesser extent than downstream splay and degree of submergence.
- (iv) For low submergence, the co-efficient is practically constant and independent of fall type and downstream splay.
- (v) Montagu type gives lower co-efficients than the C. D. O. types.
- (vi) Within the C. D. O. types the co-efficients do not differ very much, though there is a tendency for co-efficients to increase as the slope is flattened.

1 Formulae expressing the co-efficient in terms of degree of submergence and D/S splay were worked out separately for Montagu and C. D. O. types.

23. Seepage losses on Kot Nikka Branch, Lower Chenab Canal.

Kot Nikka Branch on the Lower Chenab Canal, is one of the few lined channels in the Punjab. An estimate of the seepage from some part of the lined reach was considered to be of interest, in view of the savings likely to be obtained elsewhere by similar lining. A four mile reach of the branch was selected for seepage experiments. It was found that in portions the lining was badly damaged or missing.

There are five outlets in the reach and some of these were running when the experiment was in progress. The discharges of these were measured by wooden flumes, and allowed for in the estimation of seepage. A temperature correction was also applied.

In all there were 67 pairs of observations, of which 51 were retained for examination. Out of these there were 35 taken when the outlets were closed. The remaining 16 were taken when the outlets were running.

The data were examined and it was found that the most probable value of the seepage loss, reduced to 20° C, was 4.83 cusecs with a probable error of .32, if the observations when the outlets were running are rejected. If all the observations are taken together the value came out as 4.27 cusecs with a probable error of .25. The difference is probably due to the over-estimation of the outlet discharges by the wooden flumes.

The losses work out to 6 cusecs per million square feet of wetted surface, for the days when the outlets were closed. This indicates that the maintenance of the lining in a good condition is of considerable importance.

24. Proposed seepage experiments on Dangali Distributary.

It was proposed to study the effect of lining a part of the Dangali distributary. As the material to be used cost Rs. 12,000 per mile, the advice of the Statistical Section was sought regarding the minimum length of the channel to be put under observation and the number of observations required, in order that saving by lining might be judged as significant by statistical standards.

It was assumed that:—

- (i) the seepage loss in the unlined channel was not less than 8 cusecs per million square feet of wetted surface.
- (ii) the probable error of a discharge measurement was not more than 3 per cent.
- (iii) if the lining was effective, it would reduce the seepage loss by at least 25 per cent.
- (iv) the seepage losses obeyed the normal law of distribution.

It was recommended that the length of the channel should be 3 miles and that there should be two months' observations (with six observations a day) both before and after lining.

IV.—PROBLEMS OF CONSUMPTION.

25. Relation between conductivity and total salts.

A study of the relation between conductivity and concentration for 29 soils led to the idea that at a 1 : 15 concentration, the total salts' percentage is of the same order of magnitude as the thousandth part of conductivity.

By a study of the data for 235 samples analysed at this concentration, the following tentative rules have been derived:—

Rule 1.—Conductivity (C) less than 750, then total salts per cent (S) = $C/1,000$.

Rule 2.—C greater than 750, then $S = (C/1000) + 0.1$.

These rules can be applied for finding the total salts' percentage from the value of the conductivity, which can be determined much more quickly. Generally the object of finding the total salt percentage is to pronounce on the quality of the soil. If S exceeds .2, the soil is supposed to be bad, while if it is less than .2 the soil is supposed to be good. It was found by an examination of the above data that for good soils C was less than 150 and for bad soils it was always greater than 250. When the conductivity lay between 150 and 250 the total salts were given by Rule 1, but if the result is of importance it is advisable to confirm this value by direct tests.

26. 'Specific surface' of a soil. Its relation with other soil properties. Is it superior as an index to 'Clay Content'?

The specific surface of a soil is defined as the surface of particles present in a given sample, per unit mass of the soil. The index is of considerable utility in analysis of soils, in ceramics, and in cement testing.

The determination of the specific surface involves the analysis of the sample, and the value of this index is dependent on the degree of fineness to which the analysis can be pushed. In case of analyses carried out in the Institute, it was found that very different values of this index were obtained for the same sample, according as the lower limit of analysis was .02 c.m., or .002 c.m. It has now been decided that a uniform standard of analysis be adopted for all samples, the lower limit being the same in all cases.

The utility of any soil index depends on its capability for explaining the physical and chemical behaviour of the soil. The clay content of the soil is one such index. In order to compare the respective merits of specific surface and clay content each of these two indices was correlated with each of the 11 other physico-chemical properties of the soil. The results showed that there was little to choose between the two, and that both of them could be used for forecasting all the other 11 properties of the soil. The reason for this lies in the fact that the specific surface increases with the proportion of finer particles present in the sample, and these particles constitute the clay content of the soil.

27. Graphical method for finding 'specific surface'.

The utility of the specific surface as a soil index having been established, it was necessary to find a method by which it could be calculated from the results of soil analysis. The usual method by which it could be evaluated from the formula expressing it in terms of summation percentages and diameters was fairly long, and it took about an hour to find the specific surface of one sample.

By plotting the summation percentages against the reciprocals of the diameters, passing a smooth curve through the plotted points, and estimating the area enclosed between the curve and the two axes, it is possible to determine this index much more quickly. By making certain adjustments it was possible to determine the specific surface directly from a planimeter reading of the area. The entire plotting and quadrature took about five minutes.

28. Increase in cultivated area through Drainage.

A considerable increase in cultivation on the left side of the Main Line, Lower Chenab Canal was noticed during the winter inspection. In the previous years the cultivation of this area was mostly confined to wheat in the Rabi. This year cotton was also noticed.

The Waterlogging Assistant to the Financial Commissioners was requested to verify from the revenue records the progressive increase in cultivation in this area, which had been served by the newly constructed drain.

The Superintending Engineer, Drainage, had earlier suggested that the efficiency of a drain may be measured as much by the increase of the cultivated area as by the increase in percentage run off.

The Chief Engineer desired that an enquiry as to the increased cultivation of matured areas, if any, from the revenue records be carried out, both before and after the construction of the drain. Figures for cultivated sown and matured areas for 10 villages in the tract were obtained. The data were examined in the Institute. It was found that the cultivated area was practically constant from 1934-35 to 1939-40. The area sown in Kharif, however, showed an increase of 30 per cent and the rabi area an increase of 15 per cent on the 1934 value. The crops in which there was the greatest improvement could not be specified but the noticeable increase in Kharif seemed to confirm the cultivation of cotton noticed earlier.

The increases in the area matured were of the same order, 30 per cent in Kharif and 18 per cent in Rabi.

The matured area expressed as a percentage of the cultivated area showed a consistent increase.

It appeared, therefore, that there were definite increases in sown and matured areas from 1934-35 onward and that these increases were being maintained.

29. Changes in *thur* area in 8 districts of the Punjab.

The districts chosen were, Sheikhupura, Gujranwala, Gujrat, Shahpur, Jhang, Lahore, Montgomery and Lyallpur.

It was proposed by the Land Reclamation Board to reclaim the salt stricken areas in a given number of years. If this area were constant the area to be reclaimed per year would be given by the total area divided by the number of years in which the reclamation was to be carried out. But as the *thur* (salt) in each district was increasing, an additional area equal to the probable rate of increase would also have to be reclaimed every year. The object of the investigation was to give the Land Reclamation Board an idea about the rate of increase.

The data showing the total *thur* area in each district were copied from the reports of the Waterlogging Assistant to the Financial Commissioners, given in the printed proceedings of the Waterlogging Board, for the years 1931-32 to 1939-40. The average rates of increase were worked out by finding the slopes of the straight lines fitted by the method of least squares, to the values of *thur* for each district.

It was pointed out that the average rate of increase for all the districts taken together, was nearly 28,000 acres per year. This was nearly .3 per cent or about 1/330 of the total culturable commanded area. The rate of increase was both absolutely and relatively the largest in the Sheikhupura district, being 16,840 acres or 1.36 per cent of the culturable commanded area. This was followed by Gujranwala, where the rate of increase was 6,260 acres or .62 per cent of the culturable commanded area.

30. Early closure of Kharif Channels and Rice Cultivation on the Upper Chenab Canal.

The Chief Engineer, North, wanted that the Raya Branch and other Kharif channels of the Upper Chenab Canal may be closed on the 3rd October, i.e., about 12 days earlier than the present scheduled time of closure. The object was to utilise the water released by the earlier closure, on Rabi sowing in Lower Bari Canal and additional watering to cotton in the same area.

This measure was, however, considered likely to affect the rice crop on the Raya Branch and other Kharif channels, and the Director, Agriculture, Punjab, was requested to have experiments carried out with a view to studying the effect of a shift in the last dates of irrigation from 15th October to 3rd October. The experiments were carried out by the Cerealist, Agricultural College, Lyallpur, at the Rice Farm, Kala Shah Kaku. Two varieties of rice of fine type, 370 Basmati, and 7 Mushkan, were studied, as these constitute according to the Cerealist, at least 50 per cent of the total rice area on Raya Branch. The factor studied was the yield of the crop.

Experiments were also carried out by the Superintending Engineer, Upper Chenab Canal, with a view to studying the effect of earlier closure on the yield as well as the quality of the fine and the coarse varieties.

The Institute was asked to verify the results obtained by the Cerealist, and the Superintending Engineer, Upper Chenab Canal

The points at issue can be set forward in the form of the following questions:—

- (i) If the Kharif channels on the Upper Chenab Canal are closed on 3rd October instead of on 15th October, will the area under rice shrink,
 - (a) As a whole ?
 - (b) Fine varieties only ?
 - (c) Coarse varieties only ?
- (ii) Will the earlier closure decrease the yield, per acre, of
 - (a) the fine varieties (b) coarse varieties ?
- (iii) How will the quality of the grain, i.e., its size, liability to breakage and aroma and elongation in cooking be affected by the earlier closure ?
- (iv) Can the effect, if any, of earlier closure on the yield be counteracted by planting the rice earlier by an interval equalling the shift in the date of closure ?
- (v) Can the water released by the earlier closure of the Rava Branch and other Kharif channels be utilized with greater advantage to the department and to the cultivators on the Lower Bari Doab Canal ?
- (vi) Is there a case for the introduction of an early maturing variety of rice in the tract irrigated by the Rava Branch and other Kharif channels ?

The data collected by the Cerealist and the Superintending Engineer, were examined in detail and a report prepared. The conclusions are given below —

(a) If the kharif channels on the Upper Chenab Canal are closed on 3rd October instead of on 15th October, the area under fine varieties may show a shrinkage with a corresponding gain under coarse varieties of rice. The earlier closure is not likely to make the rice area shrink as a whole.

(b) The earlier closure is likely, in dry years, to cause a decline in the yield of fine varieties. This decline is likely to be about 5—7 per cent if the transplanting is completed by 14th July and much higher if it is not completed by the beginning of August.

If there is rain in October, there may be no decline.

The yield of coarse varieties does not appear likely to suffer a decline if the last watering is shifted to 3rd October.

(c) The earlier closure may affect the 'quality' of the fine grains—as judged by per cent of seedless grains, breakage in milling and aroma and elongation in cooking—somewhat adversely.

Effect on quality.

The effect on coarse varieties is likely to be negligible

(d) The adverse effects, if any, of the earlier closure on the yields of fine rices can be minimized by a similar shift in the date of transplanting, if the latter is not

Effect of earlier planting
delayed beyond the middle of July

(e) The loss if any, to the cultivator on the Upper Chenab Canal is likely to be offset by a gain to the cultivator on the Lower Bari Doab Canal of an amount of the same order. The Irrigation Department may gain on the transaction

Loss of Upper Chenab
Canal is Lower Bari Doab
Canal's gain

(f) The introduction of an early maturing fine variety, which can be transplanted during the first fortnight of July, will reduce the loss, if any, to the Upper Chenab

Early variety needed

Canal cultivator and revenues

(g) In most years the earlier closure is not likely to be compensated by October rains

Rain will not help

(h) It is recommended that, in view of the likely importance of the shift, experiments on yield should be continued for another 2 or 3 years—both by the Cerealists and by the Superintending Engineer, Upper Chenab Canal—and that the former should also conduct tests for 'quality,' on lines similar to those followed by the Superintending Engineer, Upper Chenab Canal. He should also investigate the possibility

Experiments must continue

Chenab Canal—and

Early variety should be evolved

of an early maturing fine variety and institute experiments on coarse varieties to confirm the results obtained in Raya Division

31. Lay-outs for Experimental areas in Thal.

There are large sandy tracts in the area commanded by the Thal Project where, it was considered, the normal irrigation practice would not be successful. It had been suggested that a system of basin irrigation be introduced instead of the perennial irrigation as the former was likely to level up the sand dunes and bind the soil.

For the present, it was proposed to study the following factors at five experimental farms in the Thal area—Kundian, Bhakkar Main Line Lower, Bhakkar Canal Colony, Leiah and Khushab—

(a) Whether perennial irrigation (with or without silt) could succeed in that area and if so, which of the common crop rotations would yield the best return per unit of water applied

(b) Basin irrigation *versus* perennial irrigation

(c) Best sowing time of cotton

(d) The effect of crops requiring large quantities of water on the movement of salts

(e) The investigation of the depth of penetration of water into the soil under chahi irrigation and its effect on salt movement

Suitable designs for these experiments in randomised blocks or in the form of 'Latin Squares,' depending upon the nature of each experiments, were worked out

V.—ADVISORY STUDIES.

32. Failure and Reconstruction of the Tail fall of Nathaura Escape, Hardoi Branch.

The Nathaura Escape takes off at mile 35 of Hardoi Branch of the Sarda Canal. It is designed to take a maximum discharge of 2,000 cusecs and has an outfall into the Khanaut Nadi. There were two falls on it at mile 0·8·461 and mile 0·4·106. The latter of these is the tail fall.

Both these falls are double falls. The upper one has two steps with drops of 4 feet and 5½ feet, respectively and the tail fall had two steps with drops of 4 feet and 6½ feet. It appears from the plans that the vertical cut-offs originally provided with each fall were comparatively shallow.

The tail fall failed on 31st October, 1938. The bed retrogressed to within 50 feet of the downstream floor of the upper fall, which was, however, not damaged.

Two proposals were made for protecting the upper fall.

(a) Rebuilding the lower fall with two steps as before.

(b) Extending the talus of the upper fall in the form of a rapid.

The respective costs of these proposals were estimated at Rs. 1,05,000 and Rs. 35,000, respectively.

The proposals were examined in the Institute and Dr. Uppal suggested that the presence of the rapid at the end of the upper fall may do away with the necessity of rebuilding the tail fall. He also gave suitable values for the slope of the glacis and for the length of the horizontal floor downstream of the toe of the glacis, and also the pattern, positions, and dimensions of the staggered blocks to be placed above the floor.

The depth of the downstream cut-off needed to prevent piping and the thickness of the floor required to counteract the uplift were later worked out, after the appropriate safety factor was estimated from a grading of the bed silt samples taken at the site of the proposed fall. The glacis and the downstream floor of the rapid were as usual taken to be impervious.

The design finally evolved by the local officers was, however, for a *permeable, flexible rapid* made of wire mattresses filled with bricks, without any sheet piling at the end of the level portion. They also worked out the design for a separate tail fall, which can replace the failed structure.

Both the designs—the separate fall, and the addition of a rapid to the upper fall—were examined in detail. It was considered that the replacement of wells by lines of piling would improve both the designs considerably, and that the first design though more costly was superior.

33. Approximate Formula for finding the Slab Thickness for Bridge and Girder Spans.

The load on a bridge may be divided into—

- (a) *Dead load*, i.e., the static load due to the weight of the bridge material, and
- (b) *Live load*, i.e., the moving load due to the traffic passing over the bridge.

The 'Live Load' can again be classified as—

- (b₁) "Knife Edge Load" or "K.E. Load", i.e., load taken to be concentrated at a point.
- (b₂) "Distributed Load" or load distributed uniformly over the span.

As the live load is often likely to be applied to the bridge in a sudden and violent manner, it is usual to make an allowance for its impact on the bridge. This is done by multiplying the live load by a factor known as the "Impact Factor" and adding the product to the live load.

For a reinforced concrete bridge the depth of [the cement above the reinforcement is determined by equating the moment of resistance of the reinforced slab for each girder span to the total maximum moment of bending due to the dead and the live loads on that span. The depth thus found is increased by the depth of cement placed as a cover below the reinforcement.

The value of the depth of the cement above the reinforcement, with the Indian Roads Congress Standard Loading, was found by solving the equation obtained by Mr. Baker, Officer on Special Duty, Communications Board, and deriving an approximation.

It holds only within the following limits of the values of '1' (span of the bridge) and 's' (span of the girder). The limits are those set by Mr. Baker.

Variable.	Maximum.	Minimum.
1	60'	10'
s	10'	2½'

The approximation is:—

$$d^1 = \sqrt{3s \left(1 + \frac{9s}{100} \frac{L+50}{L+30}\right)}$$

s and 1 being the spans of the girder and the bridge, respectively. Within the ranges fixed for 1 and s it gives results identical, for all practical purposes, with those given by Baker's equation.

The maximum error from the above formulâ does not exceed $\frac{3}{4}$ per cent (relative) or $\frac{1}{8}$ inch absolute, and the actual error will be much less. The order of accuracy is, therefore, about as good as that attainable by a nomogram.

34. Stabilization of earth roads.

The stabilization of a soil road requires as a preliminary a knowledge of the optimum proportions in which the various ingredients should be present in a soil mix. The next problem usually is to find out the proportion and grading of the stabilizer which may be added to a soil of known constitution to enable it to stand up to traffic, in case it is not considered stable enough to do so on its own. The knowledge of the optimum proportions of fractions of various grades has been greatly advanced by the experiments carried out by Hogentogler, for the Division of Tests, Bureau of Public Roads, United States, America, and in the absence of any *ad hoc* experiments carried out in India, their results may temporarily be accepted as standards. The Bureau have not, however, expressed their results in a mathematical form and it was, therefore, considered desirable that a preliminary examination of these proportions may be undertaken.

The equation of the optimum curve was found by double-logarithmic plotting and correlation as, $S=82 d^{3/7}$, where S per cent of particles have diameters below d mm. The other properties of this curve were also investigated.

It was noticed that this curve required a very large proportion of particles above .6 mm in diameter. It was obvious that for soils which are rich in clay or otherwise incline to the fine side, the ratio of the weight of the coarse stabilizer, to the weight of the soil sought to be stabilized may exceed unity. The availability and transport of the large volumes of the stabilizer involved may not always be possible.

It appeared that while Hogentogler's curves might be accepted as standard in the absence of any thing better, their applicability to Punjab soils should be further examined on the following lines:—

- (i) Analyses of typical soils from all the regions where the roads are proposed to be stabilized should be carried out (in case these are not done already) and the results tabulated and plotted.

The same thing should be done with the stabilizers which are likely to be available.

- (ii) Using Hogentogler's curves and their derived properties it will then be possible to fix the percentages and the types of the stabilizers which will suit a given soil.
- (iii) If it is found that the weight of the stabilizer is, in general, greater than 10—15 per cent of the weight of the soil,

attempts may be made to see if by adding the proportions which can be economically added in the field, the resulting soil mortar does not show as good results as Hogentogler's.

35. Graphical solution for 'Flow point'.

For flow in rectangular channels the equation connecting the energy head, H , with the depth of flow, D , and the velocity of flow, V , is given by the equation

$$H = D + \frac{V^2}{2g}$$

This equation can be written as—

$$H = D + \frac{q^2}{2gD^2}$$

where q is the discharge per foot run. This equation forms a cubic in D . It can have two, one or no positive roots. The solution of this equation in terms of q and H is given in Buckley's Pocket Book of Irrigation, and involves a trigonometric function, representing an angle. This 'angle function' has been termed by Mr. Hickey, Chief Engineer, United Provinces, as a 'Flow Point.'

Mr. Hickey has applied the idea of flow point to the elucidation of certain problems in regard to the formation of standing wave and flow in regime channels. At his request the methods adopted by him have been examined. In addition a geometrical solution has been suggested, by which the flow point can easily be determined if the Energy-Depth Curve for a given value of q has been plotted.

VI.—SUMMARY AND DISPOSAL.

The more important results of each investigation, and the form in which these have been put on record, are given below:—

(a) PROBLEMS OF PRODUCTION.

1.—Jaba Failure and after.

The theoretical solution for uplift under a floor fitted with a downstream pile not driven into a clay stratum (lying below the sand on which the floor rests) is obtained.

Note not yet complete. Results will be published in due course.

2.—Sloping Toe-wall and Kalabagh Weir.

Solution for uplift and exit gradient for a work with sloping toe-wall is found, and applied to the (then) proposed case of Kalabagh Weir.

to unity both for regime and non-regime sites. To use the formula as a criterion for regime, it is necessary to study more non-regime sites and to show that the formula does not fit them as well as it does the regime sites.

Note (pages 11) sent to the *Central Board of Irrigation*. Published as part of the proceedings of the 10th meeting of the Research Committee.

14.—‘Shock’ and ‘Coherence’ in Regime Flow.

‘Shock’ is a measure of channel condition, and ‘Coherence’ of aggregation of bed particles. Using Lacey formulae, it is found that Shock per cent = $-90\sqrt{2} \log C_L$, where $C_L = V/16R^{2/3}S^{1/3}$. The effects of shock on slope and bed silt are expressed as powers of C_L . With no shock, $C_L=1$, and the silt factors f and f_q are equal. A geometrical way of representing shock is given.

Note (pages 31+1 diagram) sent to the *Central Board of Irrigation*, is under circulation.

15.—‘Most efficient’ Section.

The most efficient section, i.e., the one which for given perimeter, P , and fixed water width, W , has maximum sectional area, is not a semi-ellipse, as Mr. Lacey thought, but a segment of a circle, as shown by the Calculus of Variations.

Mr. Lacey informed. Separate note not yet ready.

16.—Khushalani’s ‘Rolling Theory’ of Flow—I.

Khushalani’s approximation is replaced by exact formulae. It is shown that using Lacey Formulae, the minimum mean sectional velocity is .852/second, as shown by Lacey, and that the section is then a semi-circle and not an ellipse as given by Khushalani.

Mr. Lacey and Professor Khushalani informed.

Note (pages 6) prepared. It will be published with later comments on ‘Rolling Theory’.

17.—Optimum Slopes for Babehali Distributary. Upper Bari Doab Canal.

The channel can run to its existing overall slope, if some coarse silt is excluded at head. A change in parent branch may not be necessary.

Note (pages 17+2 diagrams) sent to Executive Engineer, Gurdaspur Division.

18.—Silt and scour on Main Line, Lower Jhelum Canal.

The main line is in scour—6' at head to 1½ feet at tail. From 1922 to 1940 there is no scouring and the silting trouble in the distributaries lower down cannot therefore be ascribed to progressive

scouring in this reach. The channel runs to $\cdot 13$ per thousand which is what Bose's formula would give with river silt. Its regrading to a different slope seems unnecessary.

Note (pages 7+2 diagrams+8 sheets of sections) sent to the *Superintending Engineer, Lower Jhelum Canal*.

19.—Silt Distribution on Bikaner Canal.

Silt content at the lined section at R. D. 96,000, increases with depth, but there is little change with distance from the bank. The silt grade (i.e., mean size) does not appreciably change with either.

Note (pages 6) sent to Mr. T. Blench, Executive Engineer.

20.—Rugosity Coefficients on Lined Channels with special reference to the Design of Channels included in the Lower Chenab Canal Lining Project.

From an analysis of the values for 8 months, of V, R and S on the Lined Haveli Canal, a value of $\cdot 0160$ for Lacey's N was recommended for use on the Lower Chenab Canal Lining Project. The corresponding Manning and Kutter's rugosity coefficients came to $\cdot 0149$ and $\cdot 0147$, respectively.

Note (pages 24+1 diagram) sent to the *Chief Engineer, Northern Administration*.

21.—Design of Glacis Profile. I.

Montagu's profile is based on a fallacy. Besides, it gives a high vertical acceleration to the jet, which it set out to reduce. Bose's treatment is mathematically correct but does not also fulfil the second object.

Note (pages 29+8 diagrams) sent to the *Superintending Engineer, Western Jumna Canal* (Mr. A. M. R. Montagu) and to the *Central Board of Irrigation*.

22.—Discharge Coefficient, Degree of Submergence and Splay.

In the cases examined, the discharge coefficient increases with (i) decrease in degree of submergence and with (ii) increase in n , where D. S. splay is $1/n$. It was higher with Central Design Office types (slopes : vertical, $1/3$ and $1/5$) than with Montagu type.

The matter is still under investigation.

23.—Seepage losses on Kot Nikka Branch, Lower Chanab Canal.

For a 4 mile reach on this channel—lined but now in bad condition over some portions—the losses came to 6 cusecs per million square feet, from 35 sets of values. With the outlets open these drop to $5\frac{1}{4}$ cusecs (22 sets).

Note (pages 9+1 diagram) summarized for *Waterlogging Board*, Published in their printed proceedings.

water surface by about 10 feet. In the next test, the first row of the blocks instead of being at the toe of the glacis was moved to a point 10 feet downstream of the toe. The results of this arrangement are shown in Series 3 of Table 40. The depth of scour in this case was slightly less than that obtained in the previous case. The line of maximum velocity was also closer to the surface in this case. The following arrangement was found to be the most satisfactory:—

I.—One row of $5' \times 2.5' \times 2.0'$ blocks in two lines at 10' downstream of the toe of the glacis.

II.—One row of $5' \times 2.5' \times 2.0'$ at the end of the impervious floor.

Further tests were carried out on triangular instead of rectangular blocks with the object of preventing shingle accumulation on the floor. The original staggered blocks in the first row were replaced by triangular blocks, the sloping side facing upstream. The shape of the downstream row of blocks was not altered.

In order to examine the movement of shingle, coarse bajri $\frac{1}{2}$ " in diameter was introduced into the water upstream of the crest. The results for this arrangement are shown in Table 40, Series 4. It was found that most of the bajri accumulated upstream of the first row of blocks and a little which passed over the blocks accumulated on the floor down stream between the rows of blocks. From the point of view of shingle movement on the floor these triangular blocks were not satisfactory.

Different shapes of blocks as illustrated in Figure 48 were next tried.

Types of blocks examined.—The results obtained in the different cases are given in Table 40, Series 7. The shingle tests showed that the most satisfactory shape of the upstream row of blocks was that in Series 7. The arrangement is illustrated in section and in plan in Figure 49.

(ii) INVESTIGATION OF A MODEL OF KALABAGH WEIR TO DETERMINE UPLIFT PRESSURES ON THE FLOOR OF THE WEIR.

Experiments were carried out on a model of Kalabagh weir to a scale of 1/100 for determining uplift pressures on the floor of the weir under the following conditions of the sub-soil:—

(a) When the sub-soil consisted of uniform sand,
and

(b) When the sub-soil was a mixture of sand and shingle
in varying proportions.

In the first series of experiments the model was constructed on sand alone and pressures were recorded at 24 points. The discharge passing through the sand under the model was also observed. It was 1.4 cc per second or 5 litres per hour. The hydraulic gradient from the observed pressures is drawn on Figure 50.

For the subsequent tests the model was dismantled and the sand underneath the model was replaced by a mixture of coarse bayri and sand in the ratio of 1 to 1. The packing is shown in Figure 51. Pressures were observed at the same points as in the previous experiments. A plot of the observations is made in Figure 50 for comparison. The discharge was also measured in this case with the same head as before across the work and worked out to be .5 cc a second or 1.8 litres an hour.

Results—When sand underneath the work is replaced by a mixture of sand and shingle the transmission constant of the material is reduced and the pressures on the floor of the work are increased. It is shown in Figure 51 that the pressures on the upstream portion of the work are higher in the case of shingle and sand than those observed with sand alone. Considerable difficulty was experienced in obtaining a satisfactory contact between the base of the model and the underlying sand shingle mixture.

Experiments were next carried out with a percentage of shingle greater than 50. In the first experiment the shingle used was 60 per cent and sand 40 per cent and in the second case shingle 75 per cent and sand 25 per cent. In both these cases faults developed at the downstream end of the model and the contacts between the base of the model and the underlying sand shingle mixtures were unsatisfactory. This is shown in Figures 51A and 51B. Sand started to blow at the downstream end and the pressures on the work which resulted in this case, as shown in Figure 50, were very high.

In continuation, the experiments were carried out on different sizes of shingle. In the first series of experiments shingle varying between $\frac{3}{4}$ " and $\frac{1}{2}$ " was used with varying proportions of sand. The results are illustrated in Figure 52. When the shingle-sand mixture was in the proportion of 50-50, no blowing occurred at the downstream end of the model. When, however, the proportion of sand was reduced to 33 per cent and 25 per cent blowing at the downstream end of the model occurred and the pressures consequently increased considerably. In the second series of experiments shingle between $\frac{1}{2}$ " and $\frac{3}{4}$ " diameter was used and again the proportion of sand was varied. The results are shown in Figure 53. With 60 per cent shingle and 40 per cent sand mixture no blowing occurred and the pressures obtained in this case agreed with those in the 50-50 mixture used in the previous experiments. In the case of 20 per cent sand and 80 per cent shingle, blowing occurred and the pressures at the upstream portion of the model were higher than those with a 50-50 mixture.

A third series of experiments was carried out with various grades of shingle and all with a 50-50 sand shingle mixture. The results are shown in Figure 54. In all these cases no blowing occurred and the pressures observed appeared to be reasonably consistent for all grades of shingle examined.

Two gauges were erected, one close to the Nawab Bund and the second at point 'L' shown on the plan in Figure 65. A discharge equivalent to 25,000 cusecs was run in the river and bunds were put in at the mouths of the cuts so that no flow took place through the cuts. The cuts were opened and the right creek was gradually closed. Observations of water levels at both gauges were taken regularly. When the gauges became steady, a further extension of the bund was made. After completely closing off the right creek, the central creek was also closed in a similar manner. The whole operation took about 24 hours. The water levels observed are shown in Table II. From an examination of this table it will be seen that closing of the right creek causes a heading up of about 2.3 feet on the gauge at 'L'. When the central creek is also closed then the gauge at 'L' goes up by about 9.0 feet.

Determination of the directions of flow in the river upstream of the weir.—Before carrying out the tests on the divide walls it was considered necessary to ascertain the conditions of approach of the river to the weir. In order to determine the directions of flow of the bottom water, weighted soap balls of three different colours, blue, red and green were dropped into the water at the railway bridge. The red balls were placed in the river on the right side, blue were dropped in the centre and green on the left side. The discharges equivalent to 150,000, 200,000 and 300,000 cusecs were run on the model and the courses of the walls which travelled on the bed of the river were traced. This is shown in Figure 79. It will be seen from Figure 80 that the water which feeds the canal flows along the left bank for a short distance downstream of the bridge, then round the nose of the left guide bank and finally along it. Water from the right creek does not appear to travel to the canal regulator. The directions of flow for the surface water were also recorded. Lighted candle floats were photographed at night. The directions of flow as observed by this method are given in Figure 81. It will be seen from this figure that the surface floats take the same direction as the bed currents. It follows that the canal is fed only by the water flowing along the left guide bank. As a result of this experiment a site close to the nose of the left guide bank was selected for adding silt to the river for the later tests with the divide wall.

Determining the effect of varying length of divide wall on the silt entering the canal.—Divide walls of lengths 600 feet, 450 feet and 300 feet were constructed in the left undersluices at the fourth pier. A definite quantity of silt was added in the river at the nose of the left guide bank, and the silt in the canal and in the river downstream of the undersluices was collected in deep trenches. The discharges examined varied from 100,000 to 300,000 cusecs and the arrangement of gate openings adopted was as below:—

Gate openings of the weir and the undersluices during the silt tests with divide wall.

Discharge.	Left under- sluice gates.	Weir.	Gates	Right under- sluice. gates.
1	2	3	4	5
	5—7	11—19	24—35	1—7
100,000 cusecs ..	2.0	3.5	2.1	8.1
	5—7	11—19	24—35	1—7
150,000 ..	2.5	4.95	4.8	5.55
	5—7	11—19	24—35	1—7
200,000 ..	4.0	8.05	9.0	12.0

Gate opening 1—10 and 20—23 (Weir bays) was nil.

The quantity of silt added to the water in the river was 1 cft. per hour in 100,000, 1.25 cft. per hour in 150,000, 1.5 cft. per hour in 200,000 and 2 cft. per hour in 300,000. The quantities of silt collected in the river below the undersluices and in the canal downstream of the regulator are shown below:—

Silt entry into canal with different lengths of the divide wall for different river discharges.

Length of the divide wall.	100,000 cusecs.		140,000 cusecs.		200,000 cusecs.		300,000 cusecs.	
	SILT IN CFT. IN 4 HOURS.		SILT IN CFT. IN 4 HOURS.		SILT IN CFT. IN 4 HOURS.		SILT IN CFT. IN 4 HOURS.	
	Canal.	River.	Canal.	River.	Canal.	River.	Canal.	River.
600' ..	.31	.50	.60	.22	1.80	.67	8.57	4.2
450' ..	.77	.50	.32	.23	.72	.63	8.35	4.5
300' ..	.006	.102	.13	.105	.303	.57	7.6	4.22

From this experiment it will be seen that as the length of the divide wall decreases the silt entry into the canal generally diminishes. This investigation shows that a divide wall 300 feet in length situated at the fourth pier is preferable to either one of 450 feet or 600 feet.

A similar series of experiments was carried out with divide walls of varying lengths constructed at the seventh pier.

A comparison of the quantities of the silt entering the canal for the various conditions is given below:—

Silt entry into canal with different lengths of divide wall and different discharges.

Length of divide wall	SILT IN THE CANAL.	
	Divide wall at 4th pier	Divide wall at 7th pier.
DISCHARGE 120,000 CUSECS.		
600 feet ..	11.4	11.4
450 " ..	8.22	2.7
300 " ..	4.02	1.4
	4.3	2.2

Length of divide wall.			SILT IN THE CANAL.	
			Divide wall at 4th pier.	Divide wall at 7th pier.
DISCHARGE 200,000 Cusecs.				
			lbs.	lbs.
600 feet	..	..	22.2	6.0
450 "	..	..	12.4	4.0
300 "	..	..	9.5	4.4
DISCHARGE 250,000 Cusecs.				
600 feet	..	..	86.0	15.7
300 "	..	..	23.4	5.1

For the regulation Weir bays 1—3 were opened.—The velocity observations with a 606' divide wall at the fourth and the seventh pier are given below:—

Model of Kalabagh Headworks.—Velocity observations in the pocket with discharges 250,000 cusecs. Velocity in pocket in feet per second with a 600' length of the divide wall at piers 4 and 7.

Position of the divide wall.			Bay 1	Bay 2	Bay 3	Bay 4.
Pier 7 ..	Surface	..	2.21	2.21	2.79	3.10
	Middle	..	.96	1.39	1.70	1.70
	Bed	..	.	.	..	..
Pier 4 ..	Surface	..	2.20	3.10	4.37	5.33
	Middle	..	1.39	1.39	2.40	2.79
	Bed	..	.96	.96	.96	.96

The directions of flow for each case are illustrated in Figures 82—85.

In addition to taking the surface currents the conditions of the river bed in the pocket were also noted, and photographs were taken after each run. These are shown in Figures 86 and 87.

From an examination of the above data the following conclusions have been reached:—

- (a) A divide wall of 300' in length results in minimum silt entry into the canal.
- (b) The silt entering the canal when the divide wall is constructed at the seventh pier is much less than that with the divide wall at fourth pier.
- (c) The velocities in the pocket with the divide wall at the fourth pier are much higher than those obtained when the divide wall is at the seventh pier.
- (d) A silt wave forms along the guide bank up to a point 1,000 feet from the weir. After this point the silt wave travels towards the bays on the right side of the undersluices. When a divide wall is constructed at the fourth pier it intercepts the silt wave and diverts the silt into the canal. With a short divide wall at the seventh pier there is no interception of silt wave and, therefore, less silt enters the canal.

Investigation of Model of Kalabagh Headworks to determine the efficiency of the Trimmu and Modified Khonki types of silt excluders.—In the Trimmu type of silt excluder, four bays of the undersluices are covered and a divide wall 600' in length is constructed at the fourth pier. This divide wall is in addition to that 300' long placed at the seventh pier.

An attempt was made to fit one of the Haigh type of silt extractors at R. D. 500 in the canal. A larger model representing the left undersluices, left guide bank, a portion of the weir and the canal is being prepared to carry out further experiments on this extractor. With the first run of this extractor it was shown that the ducts became choked. As at present designed this extractor does not appear to be satisfactory.

The excluders were examined for various river conditions.

Condition No. 1.—In this test, the alternative designs were examined with a discharge equivalent to 100,000 cusecs in the river. The river bed in the pocket and along the guide bank was moulded to R. L. 687. The model was run for four hours in each case. Six cft. of sand were added from the sand feeder placed at R. D. 3,000 of the left guide bank. The canal discharge was maintained at 7,000 cusecs with a pond level of R. L. 692. The discharge in the outfall channel was approximately 90 cusecs. After four hours the run was concluded and the silt collected in the canal and in the trench below the undersluices was measured. For the silt in the canal separate measurements were made in the trench, in the extractor

and upstream and downstream of it. The results of the experiment are given below:—

Condition No. 1.—An examination of the efficiency of the Trimmu and Khanki types of silt excluders with 100,000 cusecs discharge in the river.

Excluder type.	U/S of Extractor.	Extractor.	D/S of Extractor.	Total silt in the canal.	In the river below the undersluices in cft.
Trimmu ..	·098	·028	·080	·212	2·80
Modified Khanki ..	..	·018	·075*	·093	2·08

*This includes the quantity of silt deposit upstream of the extractor.

From an examination of this table it will be seen that the silt entry into the canal is considerably less with the modified Khanki type of silt excluder. For similar river conditions, with the Khanki modified type only 44 per cent of that passing with the Trimmu type enters the canal.

*Condition No. 2:—*In order to further examine the indications obtained in condition No. 1, the experiments were repeated with the concentrated discharge. In order to obtain this discharge, a bund 3,800 feet long was constructed at the tenth pier of the weir. A discharge equivalent to 40,000 cusecs was run in the portion of the weir enclosed by the bund. Both types of excluders were tested. The model in each case was run for a period of two hours. Six cubic feet of sand was added during each run. The discharge through the out-fall channel of the extractor was maintained at 400 cusecs. The conditions of flow in the pocket were photographed in each case. These are shown in Figures 88 and 89. It was found that with the Trimmu type of excluder there was considerable turbulence and surging in the pocket. The turbulence originated at the nose of the divide wall and the surging action at the mouth of the tunnels. When the Khanki type was substituted for the Trimmu type, the conditions of flow became smooth. Silt measurements were made as before and the results are given below.

An examination of the efficiency of the Trimmu and Khanki Type of silt excluders with concentrated Discharge.

Type of Excluder.	SILT IN THE CANAL IN CFT.				Silt in the pit down stream of undersluice in cft.
	U/S of silt tank.	Silt tank.	D/S of silt tank.	Total silt in canal.	
Trimmu ..	1·4	·15	·42	1·92	12·5
Khanki ..	·42	·084	·28	·784	3·2

This table shows again that the silt entering the canal with the modified Khanki type of silt excluder is much less than that entering the canal with the Trimmu type. The efficiency of the excluder cannot be calculated accurately from these observations. The total quantities entering the canal are, however, comparable. It will be seen from the above table that with the Khanki type only 41 per cent of the silt passing with the Trimmu type enters the canal. The indications obtained from the previous test are confirmed by the results obtained in this test.

The conclusion drawn from the investigation is that the Khanki type of silt excluder is preferable to the Trimmu type.

The Khanki type of silt excluder also effects a considerable saving in expenditure since it is unnecessary to construct an additional divide wall of 600' in length with this type.

II.—Western Jumna Extension Project.

(2) AN INVESTIGATION OF ALTERNATIVE DESIGNS OF RAPIDS TO BE CONSTRUCTED ON THE WESTERN JUMNA CANAL MAIN LINE.

A number of rapids were to be constructed in the canal. The alternative designs are shown in Figures 90—92A. They are:—

- (1) Plain rapids.
- (2) Flumed rapid with diverging sides.
- (3) Fall-cum-rapid.
- (4) Flumed rapids with parallel sides.

Models to a horizontal and vertical scales of 1/9th were constructed. All the models were placed in a single flume one below the other so that tests could be made simultaneously. In order to determine the action on the bed, sand was placed downstream of each model for a length equivalent to about 270 feet. To record the side action, the banks of the canal below the pucca work were made of earth. The following conditions of flow were examined:—

Condition No. 1.— Full supply in the Canal—
Discharge 9,000 cusecs.

Condition No. 2.— Stage discharges—

- (1) 2,000 cusecs
- (2) 4,000 cusecs
- (3) 6,000 cusecs

The model was run for a period of four hours for a discharge of 9,000 cusecs and for three hours for the low supply discharges. Observations of the water surface profile, position of the standing wave, bed scour and the side action were made. Attempts were also made to record water surface conditions.

Condition No 1—Full supply discharge—The observations taken for a discharge of 9,000 cusecs, are plotted in Figure 93. It will be seen from this figure that the fall cum rapid type gives the lowest bed scour, the next best being the plain rapid. The flumed fall with diverging sides produced large back roller at the ends of the wing walls. The flumed fall with parallel sides is much better than the fall with diverging sides. It produces no back water. The water surface profiles are shown in Figure 94. It will be seen that the trough of the standing wave in the fall cum rapid type forms much higher up the glacis than in the other cases. The photographs illustrating the conditions after the runs are given in Figures 95 to 98.

Condition No 2—Stage discharges—(1) *2,000 cusecs discharge*—The observations obtained for a discharge of 2,000 cusecs are given in figure 99. No action was noticed either on the bed or at the sides with this discharge with all the types excepting the flumed rapid with diverging sides. In this case a mound of silt was formed with deep points on either side. The flow in this case was not uniform.

(2) *4,000 cusecs discharge*—The discharge in the models was next raised to 4,000 cusecs. From the inspection of the model it was seen that the flow was smooth in all the cases excepting the flumed rapid with diverging sides. No bed scour and very little side action took place in the remaining three types.

(3) *6,000 cusecs discharge*—The results of the observations made with this discharge are given in Figure 100. From an examination of this figure, it will be seen that bed scour is negligible in the plain rapid, in the fall cum rapid type and in the flumed rapid with parallel sides. Deep scour holes however, are formed in the flumed fall with diverging sides. The velocity of flow was not uniform in this case and there was considerable turbulence on the sides and in the centre.

Recommendation—As a result of the above study the fall cum rapid type was recommended for adoption.

(ii) AN INVESTIGATION OF A MODEL OF THE RAILWAY BRIDGE AT R. D. 65,500 MAIN BRANCH, WESTERN JUMNA CANAL

A model of the bridge to a scale of 1/7 was examined for different degrees of bed bowing. In each test the model was run for a period of four hours with a discharge equivalent to 5,155 cusecs.

Tests with three feet bowing—The depth of scour in this series of test was about six feet in the centre of the channel just downstream of the pucca floor. In this case there was no side action. The scour contours and the current directions are given in Figures 101 and 102.

Tests with two feet bowing—The tests with two feet bowing showed that the scour downstream divided into two portions one on each side of the central line as shown in Figure 103. The maximum depth of scour in this case was 3.6 feet. The scour contours are

given in Figure 104. The current directions are illustrated in Figure 105 and show that there is no side action.

Tests with one foot bowing—These tests showed that one foot bowing separated the two points of scour downstream by a greater distance than in the case of two feet bowing. The depth of scour developed in this case was also greater than that obtained with two feet bowing. The development of the two scour holes farther away from the central line than in the case of two feet bowing indicated a tendency for side action to develop and for the jet to become unstable. The scour contours and the directions of flow are given in Figures 106 and 107.

Tests with flat floor or no bowing—In this case two separate scour holes developed close to the banks, the maximum scour being 5.9' as shown in Figure 108. It will be seen that as the bowing is decreased the central scour gradually divides into two scour holes which tend to approach the sides. Action on the banks took place in this case as is shown in Figure 109.

From these tests it was concluded that the most satisfactory results would be obtained with a bowing of 2 feet.

III.—River Training and Diversion Experiments.

River conditions on the Sutlej at various headworks were examined.

(i) *River Sutlej above Pallah Headworks*—An account of the experiments carried out on this model last year was given in the Annual Report for the year ending April, 1940. The following additional experiments have now been carried out—

(1) *The determination of the effect of shortening the length of the old 'T' spur on the bed conditions along the right guide bank*—The model was moulded to the river survey of November, 1939, and the old 'T' spur was moved back so that its nose was situated on the line joining the new 'T' head spur and the right guide bank. Discharges corresponding to those experienced in June to September, 1939, were first run. Since in 1939 the highest discharge was about 87,000 cusecs the following further discharges were also run—

Discharge	Time
(a) 100,000 cusecs	10 days
(b) 120,000 cusecs	7 days

After the completion of the runs the bed was surveyed. The following indications were obtained from this test—

(i) In the new position of the spur, the flow was not concentrated at the nose of the spur and there was no back towards the right guide bank as in the case of the spur in its original position. The conditions are shown in Figure 110.

(ii) A portion of the subsidiary bela was removed while the main bela was not greatly affected. This is shown in Figure 110-A.

(iii) The deep channel continued to exist along the left guide bank.

It was concluded that no useful purpose would be served by shortening the length of the old 'T' head spur,

(2) *The determination of the effect of shortening the length of the old 'T' head spur on the re-formation of the bela and the directions of flow above the weir if the present bela were lowered to R. L. 445.*—The model was again moulded to November, 1939, but the bela along the right guide bank was kept at a level of R. L. 445. The discharges run on this model were the same as used in the previous case. The observations for the directions of flow between the new 'T' spur and the weir were taken. A survey of the bed was also made after the completion of the run. The following indications were obtained from this test.

(i) The main flow did not take place at the nose of the old 'T' spur.

(ii) There was a kick from the nose of the old 'T' spur towards the left. This is shown in Figure 111.

(iii) There was a tendency for the river bed along the right guide bank to silt up and re-form the bela as shown in Figures 111-A and B.

It was concluded from this test that shortening the length of the old 'T' spur even if the bela is lowered will not improve the conditions of flow.

An explanation suggested for the inefficiency of the old 'T' head spur when it is shortened is that the flow takes place between the Murphy spur and the 'T' head spur in its new position making an embayment upstream of the 'T' head spur. Due to this embayment the flow at the head of the spur is deflected towards the left. However, when the old 'T' head spur is in its original position the ratio of the distance between the Murphy spur and the old 'T' head spur and the length of projection of the 'T' head spur is such that no embayment can form. The main flow takes place straight from the new 'T' head to the old 'T' head spur and then to the weir.

(3) In order to study further the previous results another experiment was carried out in which the old 'T' head spur was constructed as it existed and the river bed was moulded to November, 1939. The bela along the right guide bank was scraped to R. L. 450 and the discharges experienced in 1939 were run. In addition, the following discharges were also run:—

(i) 100,000 cusecs.

(ii) 120,000 cusecs.

(iii) 166,000 cusecs.

(iv) 200,000 cusecs.

Photographs illustrating the directions of flow were taken at important stages and of the bed conditions after the run and are shown in Figures 112, 112-A, 112-B and 112-C. The river bed was also surveyed after each run. The survey is shown in Figure 113.

An examination of these photographs shows that :—

- (i) The main flow became concentrated at the old 'T' head spur.
- (ii) No embayment formed between the Murphy spur and the old 'T' head spur.
- (iii) Downstream of the old 'T' head spur the major flow took place on the right side towards the weir with discharges above 100,000 cusecs. Below a discharge of 100,000 cusecs the current along the right guide bank was, however, not very strong.
- (iv) The bed surveys showed that the bela along the right guide bank had scoured. The average bed level in the area of the bela was R. L. 445.

It was concluded from these tests that if the bela along the right guide bank was scraped to R. L. 450 flow with discharges higher than 100,000 cusecs took place along the right bank and scoured the bela. The left channel, however, silted up.

(4) *Testing the effect of a submerged balli spur at the upstream left guide bank and a leading cut in the subsidiary bela on the removal of the bela.*—A submerged balli spur, the details of which are given in Figure 114 was constructed at the right guide bank, 2,500' upstream of the weir. A leading cut was made 200 feet upstream of the nose of the spur in the subsidiary bela. The position of the cut is also shown in Figure 114-A. Experiments were carried out to determine the effect of the construction of the spur on the belas between the guide banks. The model was moulded to the survey of November 1939, and was run for the following discharges which normally represent the month of May.

Discharge.			Pond level.	Time.
(1) 1,864 Cusecs	..	..	R. L. 448.63	10 Days.
(2) 1,401 "	..	..	R. L. 448.12	10 "
(3) 2,840 "	..	..	R. L. 450.67	10 "

At important points the water levels upstream of the spur were observed and are given in Table 42. It was shown that with

these discharges there was no appreciable heading up at the position of the submerged spur. However, no development of the leading cut took place. This is shown in Figure 115. The model was next run for a period of one year. The discharges experienced in 1939 including that of 80,000 cusecs were used to represent 1940 a year of low discharges. Detailed observations regarding the current directions, and bed surveys were made for discharges of 27,000 and 80,000 cusecs. These are shown in Figures 116 and 116-A. The alterations produced in the bed are also shown in the above figures. With a discharge of 27,000 cusecs, water started flowing into the cut. The following conclusions were drawn after running the model for discharges up to 80,000 cusecs:—

- (1) The action of the submerged spur was local. Upstream of the spur the river bed in the left channel silted up as is shown by the soundings given in Figure 117. Downstream of the spur the bed scoured as is shown in Figure 117.
- (2) The cut did not develop.
- (3) Downstream of the submerged spur a small portion of the subsidiary bela, which was made erodable on the model, was washed away. At certain points the top 1' to 1.5' was also washed away.
- (4) The action at the old 'T' head spur was considerable. The whole of the river concentrated at this point. Deep scour holes occurred at the nose of this spur. The channel along the left bank opposite the spur which was deep before the construction of the new spur, silted up.
- (5) For a short distance downstream of the old 'T' head spur the main flow was on the right bank. Between the guide banks the main river was deflected towards the left and hit the left guide bank at R. D. 1,500 instead of R. D. 3,000 feet. There was an indication of the shifting of the current from the left towards the centre as is shown by a comparison of the current directions given in Figures 118 and 118 A.
- (6) Between the Murphy spur and the old 'T' head spur, the left channel in which the main river flowed before the construction of the 'T' head spur, silted up. The river became practically straight in this reach.

An important conclusion reached as a result of this experiment is that, even with low discharges such as those experienced in 1939, the conditions at the end of 1940 will show a definite improvement over the 1938 or 1939 conditions.

(2) If the bela along the right guide bank was lowered to R. L. 450 the river condition between the guide banks improved considerably. The bela was further scoured out with river discharges above 100,000 cusecs.

(3) The leading cuts through the central bela became silted.

(ii) *Investigation of a model of Panjnad Headworks and the River Panjnad downstream of the weir.*—A model of the Panjnad Headworks and the river below the weir was constructed in the experimental tray of the hydraulic laboratory. Upstream of the weir, the river below the confluence of the Sutlej and Chenab was also included. The following scales were adopted :—

Horizontal .. 1 : 550

Vertical .. 1 : 60

Experiment No. 1.—The river was moulded to a survey taken in November, 1940, and four spurs were constructed at the positions shown in Figure 126. The model was run for a period equivalent to one year. The maximum discharge run during this period was 182,000 cusecs. The current directions obtained in the case of the maximum discharge are shown in Figure 127-A. It will be seen that smooth flow took place along the noses of the spurs and the right bank. Downstream of the second pair of spurs both the banks were attacked. The conditions of the bed after the completion of the run are shown in Figure 127-B.

As a result of this experiment it was shown that the spurs recommended for the river conditions in 1939 were not suitable for the changed conditions of the river in 1940.

Experiment No. 2.—In this experiment the first pair of the spurs was constructed at R. D. 3,500' below the weir. The spurs projected into the river so that the water-way at this point was maintained at 4,500'. The second pair of spurs was constructed at R.D.7,500' below the weir. The object of this arrangement was to protect the banks as well as to train the river into a single channel. The model was moulded to the survey of November, 1940 and discharges similar to those run previously were used. The current directions with the maximum discharge of 182,000 cusecs are given in Figure 128-A. The flow along the noses of the spurs projecting from the right bank was smooth and the velocity of flow between the spurs was small. At the noses of the spurs constructed on the left side there was also smooth action. There was some attack, however, on the shank of the spur No. 2 in the initial stages of the run. This was due to the high level of the bed on the left side. As the action at the spur points developed,

It was now decided to run the model for a high river year in order to determine the alterations in the course of the river with floods. The following discharges were run :—

				<i>Time.</i>
100,000 Cusecs	..	..	..	7 Days.
120,000 "	..	..	..	4 "
150,000 "	..	..	..	2½ "
200,000 "	..	..	..	12 hours

The conditions of flow are illustrated in Figure 119. The bed surveys are plotted for each discharge and are shown in Figure 120. It will be seen from an examination of the above figures that with high discharges the flow from the old 'T' head spur took a curved course and hit the nose of the right guide bank and then flowed along the edge of the old bela towards the right side of the weir. The main channel formed on the right.

It was shown by this study that with discharges above 80,000 cusecs in the river the main current would move away from the left guide bank and a portion of the subsidiary bela might erode. At the old 'T' head spur the action would increase considerably and a deep channel would form along the right bank of the river for a length of about 600 feet downstream of the spur and a second deep channel at the nose of the right guide bank and for some distance downstream of it. This is shown in Figure 121. Upstream of the submerged spur, the left channel would continue to silt up; downstream of the spur, however, the channel would scour.

(i) *The effect of leading cut No. 1 through the subsidiary bela*—A leading cut as shown in Figure 122 was made through the subsidiary bela. The model was first run with low discharges and then with a discharge of 80,000 cusecs for a period equivalent to five days. There was no tendency for the cut to develop. It silted up as shown in Figure 123.

- (2) If the bela along the right guide bank was lowered to R. L. 450 the river condition between the guide banks improved considerably. The bela was further scoured out with river discharges above 100,000 cusecs.

- (3) The leading cuts through the central bela became silted.

(ii) *Investigation of a model of Panjnad Headworks and the River Panjnad downstream of the weir.*—A model of the Panjnad Headworks and the river below the weir was constructed in the experimental tray of the hydraulic laboratory. Upstream of the weir, the river below the confluence of the Sutlej and Chenab was also included. The following scales were adopted :—

Horizontal .. 1 : 550

Vertical .. 1 : 60

Experiment No. 1.—The river was moulded to a survey taken in November, 1940, and four spurs were constructed at the positions shown in Figure 126. The model was run for a period equivalent to one year. The maximum discharge run during this period was 182,000 cusecs. The current directions obtained in the case of the maximum discharge are shown in Figure 127-A. It will be seen that smooth flow took place along the noses of the spurs and the right bank. Downstream of the second pair of spurs both the banks were attacked. The conditions of the bed after the completion of the run are shown in Figure 127-B.

As a result of this experiment it was shown that the spurs recommended for the river conditions in 1939 were not suitable for the changed conditions of the river in 1940.

Experiment No. 2.—In this experiment the first pair of the spurs was constructed at R. D. 3,500' below the weir. The spurs projected into the river so that the water-way at this point was maintained at 4,500'. The second pair of spurs was constructed at R.D. 7,500' below the weir. The object of this arrangement was to protect the banks as well as to train the river into a single channel. The model was moulded to the survey of November, 1940 and discharges similar to those run previously were used. The current directions with the maximum discharge of 182,000 cusecs are given in Figure 128-A. The flow along the noses of the spurs projecting from the right bank was smooth and the velocity of flow between the spurs was small. At the noses of the spurs constructed on the left side there was also smooth action. There was some attack, however, on the shank of the spur No. 2 in the initial stages of the run. This was due to the high level of the bed on the left side. As the action at the spur points developed,

this attack diminished. The heading up of the water below the weir in the presence of the spurs is given below:—

Discharge	D/S gauge maintained at 12,000' below the weir.	Left guide Bank R. L.	Right guide Bank R. L.	Mean level R. L.	Mean level without spurs, R. L.	Heading up.
Cusecs.	R. L.					
60,800	329.0	332.8	331.7	332.75	331.2	1.55
92,800	331.5	331.0	334.3	334.15	333.4	.75
128,200	332.6	335.4	335.3	335.35	334.45	.90
167,100	333.9	336.0	336.4	336.20	335.45	.75
182,300	334.3	337.0	336.9	336.95	336.2	.75
215,472	334.4	337.7	337.5	337.60	336.3	1.30

It will be seen from the above table that the maximum heading up is 1.55'.

Experiment No. 3.—In this experiment two spurs projecting from each side were constructed at 7,500' below the weir. The waterway between the spurs was maintained at 4,750'. The model was moulded to the survey of November, 1940 and one complete season was run. The downstream gauge situated at 12,000' was maintained at the levels recorded for the various discharges below the weir. This gauge was determined from the water surface slope between downstream of the weir and the discharge site, at $5\frac{1}{2}$ miles from the weir. Heading up caused by the spur and the drop of water level against the shank of each spur is given in Table 43. The directions of flow were observed with discharges of 60,800, 182,000 and 300,000 cusecs and are given in Figures 129, 130 and 131. With a discharge of 300,000 cusecs, the bela was submerged and there was a tendency for the river to straighten out. The photograph of the bed after running a complete season is shown in Figure 132.

Experiment No. 4.—In this experiment the bed was moulded to the survey of November, 1940 and the spurs were constructed as in the last experiment. In addition a cut was made as shown in Figure 133. The cut was 100' \times 15'. To start with, a discharge of 60,000 cusecs was run for 3 hours to represent low discharges. Current directions for the discharge of 60,000 cusecs are given in Figure 134. The conditions are more or less similar to those obtained in the previous experiments. The cut did not develop. The heading up and drop of water level along the shank of each spur are given in Table 44. The maximum depth of scour at the noses of the spur after the completion of the run are given below:—

Left spur nose	..	R. L. of the deepest point
		312.7.
Right spur nose	..	R. L. of the deepest point
		313.6.

The current directions with discharges of 182,000 and 300,000 cusecs are shown in Figures 135 and 136. Again with these discharges the cut did not develop. The bed conditions are shown in Figure 137.

It was decided that the construction of the spur at site should be postponed to next year. The model will now be examined for the position of spurs with reference to the river bed conditions at the end of the year 1941.

(iii) *Investigation of a model of the River Sutlej 13 miles above Suleimanki Headworks to determine the methods of river diversion.*—The River Sutlej upstream of Suleimanki Headworks divides into three parts :—

- (1) The right creek ;
- (2) The central channel ; and
- (3) The left or the Hasta creek.

There was a possibility that the river might breach through its left bank and out-flanked the weir. It was decided to close the Hasta creek and divert the river into the central channel. In order to achieve this, it had been decided to construct an armoured spur near R. D. 55,000 of the left marginal bund. The spur was to have been carried on to the bela between the Hasta creek and the central channel.

As a result of the examination of the plans it was suggested that instead of constructing an armoured spur an earthen bund with pilehi protection on the upstream side close to R. D. 52,000 of the left marginal bund might suffice. In addition, pilehi spurs between R. D. 59,000 and 63,000 should also be made to assist the diversion. The bund was to be carried right across the bela between the central channel and the Hasta Creek. The curvature of the river in this reach was such that no attack would be expected at the nose of the bund. This proposal is shown in Figure 138. The Chief Engineer agreed to these proposals being examined and experiments were carried out on a model of the River Sutlej for length of 13 miles upstream of the Suleimanki weir. The scales adopted for the model were :—

Horizontal	..	..	..	..	1/150
Vertical	..	..	..	..	1/25

As the result were required urgently, it was decided to carry out the tests without first proving the model. The model was run for the following discharges :—

Cusecs.	Cusecs.	Cusecs.
1. 1,399	8. 3,028	15. 20,000
2. 1,639	9. 3,053	16. 25,000
3. 1,898	10. 4,013	17. 50,000
4. 2,045	11. 4,619	18. 80,000
5. 2,117	12. 6,038	19. 100,000
6. 2,344	13. 6,226	20. 150,000
7. 2,672	14. 10,769	21. 200,000

Gauges were observed at points shown on the plan in Figure 138. Photographs illustrating the conditions of flow as obtained on the model are given in Figures 139—147. It was noticed that no attack occurred on any portion of the bund with discharges up to 150,000 cusecs. On the results obtained the proposals for the construction of the bund were accepted.

IV.—Experiments on the Methods of silt and Shingle Exclusion and Extraction at Madhopur.

These experiments were carried out on a model of Madhopur Headworks, the River Ravi upstream of the Headworks, the Main Line, Upper Bari Doab Canal, up to the old head and the Salampur Feeder up to the Salampur Silt Ejector. The length of the river upstream of the undersluices represented on the model, was approximately 7,000' while downstream of the undersluices it was for a distance of 500 feet.

The horizontal scale adopted was 1/24. The necessary exaggeration required for the vertical scale was determined from a series of tests in which in place of the undersluices, a simple wall was built and the movement of different bed materials was examined with different distortions. It was found that when the vertical scale was exaggerated three times the general movement of all particles below $1\frac{1}{4}$ " diameter took place. As this is the grade of shingle which is most conveniently available at Mahkpur a vertical scale of $\frac{1}{3}$ was adopted for the model. Figures 148 and 149 show the completed model constructed to the above scales

The river bed was moulded to the survey of November, 1937, and was run for discharges experienced in years 1938 and 1939. As the survey for 1938 was not available, the model had to be run for a period equivalent to two years. At the end of this period a survey of the pocket and the river upstream was made and compared with that obtained on the prototype in 1939. On the whole the agreement between the model and the prototype was good excepting that certain belt formations in front of the regulator on the prototype were not reproduced on the model. The gauges in the Main Line of the canal and the Salampur Feeder agreed closely with the corresponding gauges on the prototype. After proving the model, examination of different methods of silt exclusion were made. The investigation was divided into two parts. In the first part attempts were made to exclude silt and shingle from the canal by constructing certain devices in the river and by adopting certain methods of river regulation. In the second part no attempt was made at exclusion and methods of ejecting silt and shingle from the canal were examined.

The following tests were carried out :—

PART I.

- (a) An examination of the effect on the silt and shingle entering the canal of a submerged divide wall from

undersluice pier No. 2 and extending half the length of the regulator.

- (b) The examination of the effect on the silt and shingle entering the canal of a submerged divide wall extending from the undersluice pier No. 2 and covering the full length of the regulator.
- (c) An examination of the effect of a cantilever platform in front of the Head Regulator.
- (d) An examination of the effect of a different methods of river regulation on the silt entering the canal.

PART II.

Examination of the effect of the construction of silt vanes at the Old Head on the ejection of silt from the Main Line.

PART I.

(a) *An examination of the effect of a submerged divide wall from undersluice pier No. 2 extending half the length of the regulator.*—A divide wall with the top R. L. at 1136.5 was constructed in front of pier No. 2 covering the first six bays of the regulator. A discharge equivalent to 10,000 cusecs was run on the model and the canal was maintained at full supply. The model was run for a period of six hours. It was noticed that in the initial stages of the run the silt entering the right divide was considerably less than that entering the canal in the absence of the divide wall. In the left divide, however, the quantity of silt entering the canal was not materially altered.

When the run was continued, silt and shingle rolling along the bed deposited at the divide wall and ultimately the wall became buried. At this stage the shingle and silt entered the right divide freely. The construction of the divide wall, therefore, did not effect any ultimate improvement.

(b) *Examination of the effect of a submerged divide wall from undersluice pier No. 2 covering the full length of the regulator.*—The divide wall constructed in the previous test was extended upstream so that it covered all the bays of the regulator. The discharges used and the conditions of flow, were maintained the same as in the previous test. At the beginning of the test, very little silt entered the canal but as the run progressed the divide wall became buried in shingle, as shown in Figures 150-A and B and the quantity of shingle and silt entering the canal then was considerably greater than that in the absence of the divide wall.

It was, therefore, concluded from these tests that a divide wall whether covering half or the full length of the regulator did not exclude silt and shingle from the canal. The investigations on these lines were discontinued.

(c) *An examination of the effect of a cantilever platform in front of the regulator.*—A cantilever platform projecting 16 feet into the river and covering the entire length of the regulator was fixed at the level of the crest of the regulator. The silt and shingle entry into the canal was examined in the presence of the cantilever platform under river conditions similar to those pertaining when the platform was absent. It was found that in the early stages of the run very little shingle and silt went into the canal but as the run progressed, shingle started accumulating in front of the platform and passed into the canal. The level of the ramp, however, was the same as that of the platform. The ramp was most developed in front of Bays 6 to 12. These tests were discontinued as it became clear that a permanent solution would not be obtained by this method.

(d) *An examination of the effect of different methods of river regulation.*—The following different methods of regulation were tested on the Madhopur Pocket Model:—

- I *Wedge from the left*, i.e., Bay No. 1 of the undersluices was opened by 7 feet followed by Bays Nos. 2 and 3, etc., for the escape of surplus water in the river.
- II *Wedge from the right*, i.e., Bay No. 12 was opened 7 feet followed by Bays Nos. 11 and 10, etc.
- III. *Wedge from the right combined with dropping of some shutters of the supply weir.*

The tests were carried out with discharges equivalent to 10,000; 13,000; 15,500 cusecs in the river. The gate openings adopted in each case are given in Table 45. In addition to the above tests an experiment was also made in which no water escaped below the undersluices and the discharge in the river was just enough to feed the canal at the full supply level.

For each test the model upstream of the regulator was moulded to the survey of July 27, 1940. In the pocket the bed was maintained roughly at R. L. 1131-1132. This represented approximately the conditions of the pocket after a sluicing closure. The model was run for two hours in each case and a pond level of R. L. 1143.5 was maintained. In order to provide for bed equilibrium during a period of two hours 8 cubic feet of sand were added to the water at the upstream end of the model in the case of 10,000 cusecs and 10 cubic feet for 12,900 cusecs and 12 cubic feet for 15,500 cusecs discharge.

The silt entering the bays of the head regulator was entrapped in silt trenches constructed downstream of the glacis of the regulator. Each bay had a separate trench $2.5' \times 1.5' \times .8'$ as shown in Figure 151. In addition to the use of the trenches for collecting silt, sampling was also performed downstream of each bay of the regulator. Samples were taken by means of a special bucket placed along the

sloping glacis. The samples taken from each bay were analysed and the silt expressed as ounces per cubic foot of water. During the course of each run, directions of flow in the pocket were recorded by means of luminous floats. At the end of the run a survey of the pocket and of the river bed a short distance upstream of it, was made.

The observations for different cases are compared in Tables 46, 47 and 48 and shown in Figures 152, 153 and 154. Photographs illustrating the conditions of the pocket are shown in Figures 155—157. The conclusions obtained in each case are discussed below:—

I. *Wedge from the left.*—When the method of regulation adopted was wedge from the left, the following indications were obtained:—

- (1) The right divide carried a greater quantity of silt than the left divide. Bay No. 4 appeared to take the largest quantity of silt. In one case Bay No. 2 has the largest share (Table 39 Column 2).
- (2) The medium silt was slightly greater in the left divide than that in the right divide for discharges of 13,000 and 15,000 cusecs.
- (3) There was a concentrated silt wave in front of Bays 3 and 4 of the canal regulator as shown in Figure 158.
- (4) The ramp levels were usually high.

II. *Wedge from the right.*—When a wedge from the right was adopted the indications obtained were:—

- (1) The total quantity of silt passing into the canal with this method of regulation was much less than that obtained with the previous method.
- (2) The bays of the right divide carried a very small quantity of coarse silt. The quantity of silt going into the left divide was also reduced with this method of regulation but the left divide now carried a greater quantity than the right divide.
- (3) The flow in the pocket was much more evenly distributed than that in the previous case.
- (4) The ramp levels were lower in this case.
- (5) No marked shoal formation took place in front of the bays of the undersluices towards the left.

III. *Wedge from the right combined with dropping of some shutters of the Supply Weir.*—The opening of the undersluices gates in II was reduced and shutters were dropped to pass the surplus water. The following indications were obtained in this case.

- (1) The quantity of silt carried into the canal was much less in this case than in methods I or II.
- (2) The ramp levels were also lower than those obtained in I or II.

An important conclusion obtained from an examination of the above data is that much less coarse silt entered the canal bays when the system of regulation was wedge from the right and if some shutters were also dropped, the silt entering the canal was still further reduced.

The conditions in the pocket with the wedge from the right appeared to be similar to those obtained when the discharge in the river was just enough to feed the canal. In order to verify this a run was made with a discharge of 7,500 cusecs in the river, the canal running full supply. Observations for silt entering the canal, current directions in the pocket and the conditions of the bed were taken and compared with those obtained in II. The comparison confirmed the view that when the system of opening was wedge from the right water just enough to feed the canal reached the head regulator.

Examination of the effect of the construction of silt vanes at the Old Head on the ejection of silt from the Main Line.—A wall dividing the canal into two portions exists from the head regulator for a distance of 2,200 feet. The tail of the divide wall for a length of 70 feet was dismantled and a number of silt vanes were constructed as shown in Figure 159. The canal was run at full supply and silt was fed into the canal downstream of the head regulator at the rate of four cubic feet per hour. Arrangements were made for collecting the silt in the canal downstream of the Old Head and in the Salampur Feeder. On the completion of the run it was found that most of the silt in Main line was directed by the vanes into the Salampur Feeder. On determining the efficiency of each vane it was found that, counting from the right, the third and the sixth vanes were very effective in ejecting silt from the Main Line while the remaining four vanes ejected very little. This is shown in Figure 160. During the course of the run observations were also made on the current directions in the Main Line downstream of the divide wall. It was shown that:—

- (i) All surface floats continued in the Main Line below the Old Head.
- (ii) Most of the bottom floats in vanes Nos. 3, 5 and 6 went into the Salampur Feeder.
- (iii) Some of the bottom floats in the 6th vane jumped over the vane and continued down the Main Line.

A detailed study of the conditions of flow existing in the Main Line a short distance upstream of the Old Head showed that, due to the presence of the curved divide wall the silt concentrates along the right divide wall and along the left bank of the canal in the left divide, both being on the inside of the curve. This is shown in Figure 161. In view of this all vanes excepting the third and the sixth were removed and tests were carried out as before. It was shown that most of the silt and the shingle could be ejected by these vanes. Some silt, however, jumped over the central vane which was No. 3 in the previous

test. In order to trap this silt also a small vane was built between the central vane and the right vane and is shown in Figure 162. An extension of the end vane upstream, further improved the conditions.

Further tests were made with the vanes curved upstream. The model was run, and, as before, a mixture of shingle and silt was added in the Main Line below the head regulator. It was found that the projection of the vanes produced greater turbulence and, hence, more silt went into the Main Line. The top R. L. of the vanes was, therefore, fixed at 1125.5. A detailed test was made with larger quantities of silt and shingle, i.e., 20 cubic feet per hour, added at the head. It was found that even with this high charge of shingle and silt, very little went into the Main Line. This is shown in Table 49. An inspection of the model after the completion of the run showed that large quantities of silt and shingle deposited between the vanes and very little moved into the Salampur Feeder.

In order to induce the silt to move into the Salampur Feeder, in the subsequent tests the crest of the Salampur Feeder was lowered by 1.5'. The bed of the canal on which the vanes were constructed was made pucca and joined to the new crest of the Salampur Feeder in order to provide a steeper slope in this reach. It was found that with these alterations all the silt and shingle which was diverted by the vanes, moved into the Salampur Feeder. The efficiency of the vanes, based on particles of 0.2 mm., was found to be 60 per cent.

Observations of the velocities of flow against the walls of the vanes were made. The results are given in Table 50. It is shown in this table that the velocity of water flowing against the first vane is 10 feet per second while against the second and the third it is only 4.5 feet per second.

As a large quantity of silt and shingle would be diverted into the Salampur Feeder, it was necessary to determine whether the silt ejector of the Salampur Feeder could deal with the additional quantity. In order to examine this, the model was run as before and a mixture of silt and shingle at the rate of 20 cubic feet per hour was added to the Main Line.

Before the close of the run the efficiency of the Salampur Feeder silt ejector was determined according to the method used in the previous test. The efficiency worked out to be 77 per cent based on particles above 0.2 mm. The silt collected in the tank downstream of the ejector was also measured. It was concluded from these tests that it will not be necessary to re-model the existing ejector in order to deal with the additional load due to the construction of the silt vanes in the Main Line. The exact positions and the dimensions of the silt vanes are shown in Figure 163.

An examination of methods to increase the efficiency of the Salampur Feeder Silt Ejector.—An inspection of the Salampur Feeder during a sluicing closure showed that there was a deposit of shingle and silt

An important conclusion obtained from an examination of the above data is that much less coarse silt entered the canal bays when the system of regulation was wedge from the right and if some shutters were also dropped, the silt entering the canal was still further reduced.

The conditions in the pocket with the wedge from the right appeared to be similar to those obtained when the discharge in the river was just enough to feed the canal. In order to verify this a run was made with a discharge of 7,500 cusecs in the river, the canal running full supply. Observations for silt entering the canal, current directions in the pocket and the conditions of the bed were taken and compared with those obtained in II. The comparison confirmed the view that when the system of opening was wedge from the right water just enough to feed the canal reached the head regulator.

Examination of the effect of the construction of silt vanes at the Old Head on the ejection of silt from the Main Line.—A wall dividing the canal into two portions exists from the head regulator for a distance of 2,200 feet. The tail of the divide wall for a length of 70 feet was dismantled and a number of silt vanes were constructed as shown in Figure 159. The canal was run at full supply and silt was fed into the canal downstream of the head regulator at the rate of four cubic feet per hour. Arrangements were made for collecting the silt in the canal downstream of the Old Head and in the Salampur Feeder. On the completion of the run it was found that most of the silt in Main line was directed by the vanes into the Salampur Feeder. On determining the efficiency of each vane it was found that, counting from the right, the third and the sixth vanes were very effective in ejecting silt from the Main Line while the remaining four vanes ejected very little. This is shown in Figure 160. During the course of the run observations were also made on the current directions in the Main Line downstream of the divide wall. It was shown that:—

- (i) All surface floats continued in the Main Line below the Old Head.
- (ii) Most of the bottom floats in vanes Nos. 3; 5 and 6 went into the Salampur Feeder.
- (iii) Some of the bottom floats in the 6th vane jumped over the vane and continued down the Main Line.

A detailed study of the conditions of flow existing in the Main Line a short distance upstream of the Old Head showed that, due to the presence of the curved divide wall the silt concentrates along the right divide wall and along the left bank of the canal in the left divide, both being on the inside of the curve. This is shown in Figure 161. In view of this all vanes excepting the third and the sixth were removed and tests were carried out as before. It was shown that most of the silt and the shingle could be ejected by these vanes. Some silt, however, jumped over the central vane which was No. 3 in the previous

test In order to trap this silt also a small vane was built between the central vane and the right vane and is shown in Figure 162 An extension of the end vane upstream, further improved the conditions.

Further tests were made with the vanes curved upstream. The model was run, and, as before, a mixture of shingle and silt was added in the Main Line below the head regulator It was found that the projection of the vanes produced greater turbulence and, hence, more silt went into the Main Line The top R L of the vanes was, therefore, fixed at 1125 5 A detailed test was made with larger quantities of silt and shingle, i e, 20 cubic feet per hour, added at the head It was found that even with this high charge of shingle and silt, very little went into the Main Line This is shown in Table 49 An inspection of the model after the completion of the run showed that large quantities of silt and shingle deposited between the vanes and very little moved into the Salampur Feeder

In order to induce the silt to move into the Salampur Feeder, in the subsequent tests the crest of the Salampur Feeder was lowered by 1 5' The bed of the canal on which the vanes were constructed was made pucca and joined to the new crest of the Salampur Feeder in order to provide a steeper slope in this reach It was found that with these alterations all the silt and shingle which was diverted by the vanes, moved into the Salampur Feeder The efficiency of the vanes, based on particles of 0 2 mm, was found to be 60 per cent

Observations of the velocities of flow against the walls of the vanes were made The results are given in Table 50 It is shown in this table that the velocity of water flowing against the first vane is 10 feet per second while against the second and the third it is only 4 5 feet per second

As a large quantity of silt and shingle would be diverted into the Salampur Feeder, it was necessary to determine whether the silt ejector of the Salampur Feeder could deal with the additional quantity In order to examine this, the model was run as before and a mixture of silt and shingle at the rate of 20 cubic feet per hour was added to the Main Line

Before the close of the run the efficiency of the Salampur Feeder silt ejector was determined according to the method used in the previous test The efficiency worked out to be 77 per cent based on particles above 0 2 mm The silt collected in the tank downstream of the ejector was also measured It was concluded from these tests that it will not be necessary to re model the existing ejector in order to deal with the additional load due to the construction of the silt vanes in the Main Line The exact positions and the dimensions of the silt vanes are shown in Figure 163

In examination of methods to increase the efficiency of the Salampur Feeder Silt Ejector—An inspection of the Salampur Feeder during a sluicing closure showed that there was a deposit of shingle and silt

10 feet downstream of the toe of the glacis. In Bays 5 to 10 this row consisted of 2 lines of staggered blocks while in Bays 1 to 4 and 26 to 29 it consisted of 3 lines of staggered blocks. The second row of staggered blocks at the end of the pucca floor was of no use in reducing scour downstream in the presence of the existing baffle wall. In the construction of the second row of staggered blocks at the end of the pucca floor was desired to add weight to the downstream floor this could be constructed as its presence did not increase the bed scour. The most satisfactory arrangement of staggered blocks for reducing the action downstream for the different bays is shown in Figure 174-A, B and C. The arrangement for the downstream row of blocks, if it was required, is also shown in the above figures.

TABLE 37.

(Plain floor.)

Discharge intensity	U/S W S I	U/S total energy line	D/S W S L	Position of standing wave	Maximum depth of scour
Cusecs	R L.	R L	R L		Feet
268	693 1	695 99	692 0	12 from the d/s edge of crest	13 6
322	694 91	698 37	693 3	17 from the d/s edge of crest	17 0
310	694 51	693 01	693 0	Ditto	16 "

TABLE 38.—(With rectangular staggered blocks).

Discharge intensity.	U/S W. S. L.	U/S total energy line.	D/S W. S. L.	Portion of standing wave.	Size of blocks.	Position of blocks.	Maximum depth of scour.	Remarks
Cusecs.	R L	R L	R L				Feet.	
268	693 1	695 99	692 0	11' from the d/s edge of crest	5' x 2' x 2'	At the toe of the d/s. glacia.	10.18	Accumulation of single takes place at the toe of the glacia and near the blocks in all these cases.
322	694 91	698 37	693 3	15' d/s edge of crest.	5' x 2' x 2'	Ditto	13.8	
310	694 51	698 01	693 0	Ditto	5' x 2' x 2'	Ditto	13.7	
268	693 1	695 99	692 0	10' from the d/s edge of crest.	(1) 5' x 2' x 2'	(*) 20' from the toe of the glacia.	6.7	
					(2) 5' x 2' x 2'	(*) End of inverted filter.	9.4	
322	694 91	698 37	693 3	15' from the d/s edge of crest.	5' x 2' x 2'	Ditto	9.28	
310	694 51	698 01	693 0	Ditto	5' x 2' x 2'	Ditto	6.46	
268	693 1	695 99	692 0	10' from the d/s edge of crest	(1) 5' x 2' x 2'	(*) 10' from the toe of glacia.		
					(2) 5' x 2' x 2'	(*) End of inverted filter.	8.53	
322	694 91	698 37	693 3	15' from the d/s edge of crest	5' x 2' x 2'	Ditto		

TABLE

Discharge per foot run.	Upstream water level	Upstream total energy line	Downstream water level	Distance of the stand- ing wave from the toe of the glacis.
Cusecs	R. L.	R. L.	R. L.	
330	694.5	698.4	692.0	2 u/s
396	697.0	700.1	694.2	Toe
375	695.5	698.6	693.04	Do
450	698.0	701.7	696.4	Do
330	694	696.4	692.0	2 u/s
396	697.0	700.1	694.92	Toe
375	695.5	698.6	693.04	Do.
450	698.0	701.74	696.4	Do
330	694.5	696.4	692.0	2 u/s
396	697.0	700.1	694.92	Toe
375	695.5	698.6	693.04	Do
450	698.0	701.74	696.4	Do
330	694.5	696.4	692.0	2 u/s
396	697.0	700.1	694.92	Toe
375	695.5	698.6	693.04	Do
450	698.0	701.74	696.4	Do
330	694.5	696.4	692.0	2 u/s
396	697.0	700.1	694.92	Toe
375	695.5	698.6	693.04	Do
450	698.0	701.74	696.4	Do
330	694.5	696.4	692.0	2 u/s
396	697.0	700.1	694.92	Toe
375	695.5	698.6	693.04	Do.
450	698.0	701.74	696.4	Do.
330	694.5	696.4	692.0	2 u/s
396	697.0	700.1	694.92	Toe
375	695.5	698.6	693.04	Do.
450	698.0	701.74	696.4	Do.
330	694.5	696.4	692.0	2 u/s
396	697.0	700.1	694.92	Toe
375	695.5	698.6	693.04	Do.
450	698.0	701.74	696.4	Do.

Position of the Upstream row of blocks.	Position of the downstream row of blocks.	Depth of maximum scour below the d/s floor level.	Depth of the maximum velocity line from the water surface.	REMARKS.
		Feet.	Feet.	
No blocks	No blocks .	32.5	18	Series 1.
Ditto	Ditto	32.4	16	
Ditto	Ditto	32.8	18	
Ditto	Ditto ..	31.1	20	
Toe of the glacier ..	End of floor ..	14.0	6	Series 2.
Ditto .. .	Ditto	14.2	10	
Ditto	Ditto	16.2	6	
Ditto .. .	Ditto	10.2	12	
10' d/s of the toe of the glacier.	Ditto	11.7	6	Series 3.
Ditto ..	Ditto	13.8	8	
Ditto ..	Ditto	14.0	8	
Ditto .	Ditto	9.4	8.5	
Sloping blocks two lines at 10' d/s of the toe	Ditto .	13.2	10	Series 4.
Ditto	Ditto .	11.7	8	
Ditto	Ditto .	12.0	10	
Ditto	Ditto ..	12.0	10	
Blocks sloping both sides at 10' d/s of the toe of glacier	Ditto .	14.0	12	Series 5.
Blocks sloping both sides at 20' d/s of the toe of glacier.	Ditto ..	14.8	12	
Sloping blocks 2' high at 10' d/s of the toe of glacier.	Ditto ..	12.1	10	Series 6.
Sloping blocks 10' d/s of toe of glacier.	Ditto ..	11.5	10	Series 7.
Ditto	Ditto ..	11.1	8	
Ditto	Ditto ..	11.8	12	
Ditto	Ditto ..	11.6	12	
Sloping blocks 10' u/s of toe of glacier.	Ditto ..	10.7	10	Series 8.
Ditto	Ditto ..	9.3	12	
Ditto	Ditto ..	9.4	10	
Ditto	Ditto ..	9.5	10	

TABLE 41—Model of Kalabagh Weir.

WATER LEVELS IN FRONT OF NABAB'S BUND AND AT JOINTS AT THE MOUTH OF THE CUT DURING THE RIVER DIVERSION WITH A DISCHARGE OF 5,000 CUSECS

Time of observation.	(condition of the bund before construction)	R. L. of water surface at N. gauge	R. L. of water surface at S. gauge	HEADING UP WITH EACH BUNDING UP		Condition of the bund	WATER SURFACE R. L.		HEADING UP IN FEET BY CLOSING THE CENTRE CREEK	
				N. bund	Feet		N. bund gauge	S. Gauge	N bund	Feet
11 AM		Feet	1 feet	1 feet						Feet
11-30		841.1	832.3				800.2	680.9		
7-33	Main creek bund 300 feet	83.9	82.1				90.3	90.2		
7-45		83.9	82.1				90.8	90.7		
7-55	Main creek bund 500 feet	83.9	82.1				91.0	90.9		
8-00		84.4	82.3				91.4	91.2	..	
8-5		84.45	82.4							
8-7		84.5	82.45				91.4	91.2	91.3	
8-10		84.6	82.5						91	
8-15		84.7	82.6							
8-21		84.75	82.6							7.6

Station	Description	84 75	82 6	85	50
8-30	.	84 75	82 6	85	50
8-35	Main creek bund, 680 feet	85 05	82 9	.	.
8-45	.	85 15	82 95	.	.
8-50	.	85 2	83 0	.	.
8-55	.	85 25	83 0	.	.
9-00	.	85 25	83 0	1 05	50
9-5	Main creek bund, 900 feet	85 8	83 5	.	.
9-10	.	85 9	83 7	.	.
9-15	.	86 0	83 9	.	.
9-20	.	86 05	83 85	2 15	1 75
9-45	Main creek bund, 930 feet	86 4	84 1	.	.
9-50	.	86 4	84 1	2 5	2 10
10-00	Main creek bund, 1 020 feet	86 7	84 35	.	.
10-12	.	86 8	84 4	2 90	2 30
10-17	Channel completely closed 1 050	87 2	84 9	3 3	2 8
10-22	Centre creek partly closed	87 4	85 4	.	.
10-38	.	87 4	85 4	.	.
11-30	.	87 4	85 5	.	.
11-50	.	87 4	85 5	.	.
12-0	.	87 4	86 2	.	.
12-7	.	87 4	86 1	.	.

TABLE 41-A.
Model of Kalabagh Headworks.
VELOCITY OBSERVATIONS IN THE CUTS

Condition of experiment.	Cut E	O	M.	N	K.	J	C.
VELOCITY IN FEET PER SECOND							
Right creek partially bundled	2 63	86/					
Length of bund increased to 550	3 99/	3 13					
Bund extended to 631	5 65	7 89/				2 40	
Centre creek partially bundled	61/	5 15				3 87	
Centre creek completely bundled	4 92	3 72			8 83/		3 43
	9 95	5 75	6 70		6 92	11 27	3 41/
		9 91					3 45

TABLE 41-B.
Model of Kalabagh Weir.
DIMENSIONS OF THE CUTS EXAMINED ON THE 26TH MARCH, 1941

Distance from the mouth of the cut	Cut E		Cut O		Cut M		Cut N	
	Centre creek partially bundled	Completely bundled	Partially bundled	Completely bundled	Partially bundled	Completely bundled	Partially bundled	Completely bundled
0	158	317	283	375	183		175	246
1 000	151	317	233	368	91		125	246
2 000	166	317	211	477	175		175	
3 000	280	251	211	468	142			
4 000	175	57	241	468				
5 000	17	708						
6 000		3						

TABLE 42.

Discharge	Full level m/s. need.	Submerged spur point	WATER LEVELS			
			L. G. B. 3350	T. Spur U/S Nose	Slurp Spur Nose	New T. Spur Nose
1500	L. L.	R. L.	L. L.	R. L.	R. L.	L. L.
141	448 6	419 0	419 15	419 5	419 0	450 0
136	448 0	448 0	448 0	448 15	448 25	448 35
	450 0	451 0	451 1	451 2	451 35	451 35

TABLE 43.

Discharge.	LEFT SPUR.			Head across Shank.	RIGHT SPUR.			Head Across Shank.	L. G. R.	R. O. R.	Heading up.
	U/S Nose.	U/S of Shank.	D/S of Shank.		U/S Nose.	U/S of Shank.	D/S of Shank.				
Charge	R. L.	R. L.	R. I.	Feet.	R. L.	R. L.	R. L.	Feet.	R. L.	R. L.	Feet.
60,500	311 3	331 8	329 2	2 6	331 5	332 1	331 0	1 1	332 5	332 0	1 3
72,500	32 4	33 2	31 7	1 5	32 8	33 3	32 3	1 0	34 0	34 0	0 6
124,200	33 6	34 5	32 9	1 0	34 0	34 5	33 5	1 0	35 4	35 4	0 90
167,100	34 8	35 3	34 1	1 2	35 3	35 0	34 8	0 8	36 3	36 4	0 90
192,300	35 2	36 0	34 7	1 2	36 0	36 2	35 4	0 8	37 0	37 2	0 90
215,672	35 3	36 3	34 9	1 4	36 0	36 5	35 8	0 7	37 6	37 2	1 1
230,000	35 4	36 4	37 9	9	36 8	36 3	36 3	0 6	40 8	39 5	..

Madhopur
STATEMENT SHOWING SILT ENTRY INTO

Method of Result on Row No	WEDGE FROM LEFT				Bed silt collected in trenches in cubic feet	WEDGE FROM			
	1	2	3	4-12		1-9	10	11	12
	7 0	2 5	2 2	1		SIL 2 0 2 5 7 0			
	Silt in suspension					Silt in suspension			
	Above 2 mm	Between 2 mm and 0.75 mm			Above 2 mm	Between 2 mm and 0.75 mm.			
1	015	463		34	0	23			
2	009	521		061	001	240			
3	055	609		088	008	335			
4	142	916		330	011	431			
5	063	429		330	110	35			
6	056	651		142	013	504			
Total & Right Drive	334	3 364		051	14%	2 004			
7	036	533		210	014	419			
8	021	624		091	014	571			
9	017	517		064	014	439			
10	009	322		056	014	504			
11	019	673		250	014	473			
12	015	509		500	010	474			
Total on Left Drive	117	3 109		091	184	2 613			
Average	022	006			0.01	023			

46.

Pocket Model.

CANAL WITH DIFFERENT METHODS OF REGULATION.

Discharge in River, 10,000 cusecs.

EIGHT.	WEDGE FROM RIGHT AND SOME SHUTTER DROPPED.			WEDGE FROM RIGHT AND SOME SHUTTER DROPPED.		
	<div> <div>1-9 10 11 12</div> <div>NIL .5 1.5 2 0</div> <div>SHUTTERS DROPPED.</div> </div>			<div> <div>12 11 1-10</div> <div>4.0 1.5 NIL 8</div> <div>SHUTTERS DROPPED.</div> </div>		
	Silt in suspension.			Bed silt in trenches in cubic feet		
	Above .2 mm.	Between .2 and .075 mm.	Bed silt in trenches in cubic feet	Above .2 mm	Between .2 and .075 mm.	Bed silt in trenches in cubic feet.
Bed silt in trenches in cubic feet.						
.001	.202	.292	Nil	.013	.186	.001
.002	.004	.287	.002	.013	.175	.004
.003	.010	.320	.011	.012	.191	.006
.017	.014	.549	.024	.013	.220	.004
.012	.013	.408	.012	.013	.196	.003
.000	.011	.424	.001	.009	.129	.002
.042	.064	2.280	.051	.073	1.097	.020
.035	.008	.447	.090	.011	.129	.026
.070	.007	.449	.078	.023	.163	.010
.060	.005	.530	.082	.009	.127	.043
.037	.027	.493	.077	.021	.176	.071
.190	.016	.305	.250	.004	.216	.130
.250	.009	.562	.303	.009	.175	.420
.692	.071	2.756	.877	.077	.977	.700
..	.026	.788	..	.004	.319	..

TABLE
Madhopur Pocket

(1) STATEMENT SHOWING SILT

Bay No.		13 8-40.							Bed silt in trenches in cubic feet.
		1	2	3	4	5	6	7-12	
		7 0	6 0	5 0	4 0	3 0	1 5	NIL	
		Silt in suspension.							
		Above .2 mm.			Between .075 and .2 mm.				
1		.040			.412			NIL	
2		.306			.395			.15	
3		.238			.510			.75	
4		.133			.405			1.15	
5		.154			.333			1.21	
6		.221			.342			.71	
Total Left Divide ..		1.692			2.487			3.970	
7		.200			.448			.42	
8		.150			.541			.30	
9		.109			.461			.25	
10		.046			.304			.043	
11		.058			.445			.370	
12		.080			.505			.50	
Total Right Divide ..		.643			2.704			1.833	
Approach .. ..		.200			.03			.0

47.

Model.

ENTRY INTO CANAL.

WITH SUBMERGED BELA MADE. 14 8-40.							Bed silt in trenches in cubic feet.	DISCHARGE IN RIVER 13,000 CUSECS 15 8-40.							Bed silt in trenches.
1-6	7	8	9	10	11	12		1-9	10	11	12	1-16			
CLOSED								NIL	5 0	6 0	7 0	..			
								SHUTTERS DROPPED.							
Silt in suspension.							Silt in suspension.								
Above .2 mm.			Between .075 and .2 mm.					Above .2 mm.		Between .075 and .2 mm.					
.030			.328				.010	.018		.233			.002		
.036			.409				.020	.016		.239			.011		
.032			.386				.019	.016		.327			.011		
.070			.482				.062	.025		.332			.036		
.050			.394				.046	.023		.305			.030		
.050			.416				.004	.034		.377			.002		
.268			2.415				.161	.135		1.808			.092		
.080			.455				.233	.026		410			.150		
.092			.497				.325	.036		.369			.125		
.087			.405				.317	.016		.231			.142		
.063			.429				.200	.046		.406			.100		
.076			.541				.375	.019		.310			.250		
051			.480				.583	.014		.341			.267		
.449			2.807				2.033	.157		2.067			1.034		
.049			.443				..	.041		445			..		

SILT ENTERING BAYS OF THE HEAD REGULATOR

Underslaucies gate openings Bays of the regulator		16840					Bed silt in trenches in cubic feet.
		1-2	3-4	5-6	7-8	9-12	
		70	50	40	11	VIL	
		Above 2 mm		Between 075 and 2 mm			
1		016		263		Nd	
2		038		290		08	
3		108		292		46	
4		137		243		77	
5		068		236		08	
6		135		215		80	
Total of the right divide		502		1589		219	
7		097		271		33	
8		043		288		61	
9		079		264		42	
10		069		364		25	
11		062		206		30	
12		014		206		30	
Total of the left divide		314		1749		220	
Approach		017		362			

48.

Pocket Model.

WITH DIFFERENT SYSTEMS OF REGULATION.

River Discharge .. = 15,500 cusecs.

Canal Discharge .. = 7,500 cusecs.

18-8-40.			19-8-40.		
1-4 1.1	5-6 4.0	7-8 5.0	9-10 7.0	11-12 7.0	Bed silt in trenches in cubic feet.
Above 2 mm.	Between 0.75 and 2 mm.				
.010	.361	.002	.013	.420	.006
.010	.323	.013	.013	.363	.013
.015	.373	.014	.017	.432	.015
.028	.558	.056	.018	.413	.037
.015	.404	.044	.023	.631	.026
.135	.566	.006	.019	.722	.015
.213	2.585	.135	.103	2.081	.112
.084	.473	.202	.018	.680	.150
.036	.455	.417	.010	.475	.700
.031	.449	.295	.019	.505	.170
.010	.459	.167	.034	.668	.250
.010	.496	.267	.063	.958	.440
.011	.487	.292	.011	.555	.420
.182	2.860	1.730	.155	3.831	1.630
.018	.768	1.865	.014	1.972	1.742

SHUTTERS DROPPED.

Bed silt
in
trenches
in
cubic feet.

TABLE 49.

Model of Madhopur Pocket, Upper Bari Doab Canal, Main Line and Salampur Feeder.

WORKING OF SILT VANES.

Date.	Silt in cubic feet added in the two divides.	Silt in cubic feet in the Main Line Custer.	Silt deposited in the two divides in cubic feet.	Silt deposited in the Salampur Feeder in cubic feet.	Silt collected in the Salampur Feeder Silt ejector in cubic feet.	Silt collected in the vanes in cubic feet.
21st April, 1940	21	1.00	.37	2.85	7.00	7.00+3.00
23rd April, 1940	20	.75+.20	..	..	12.00	4.80

TABLE 50.

Model of Madhopur Pocket, Upper Bari Doab Canal, Main Line and Salampur Feeder.

STATEMENT OF VELOCITIES OBSERVED ALONG THE VANES.

Distance along the vane from the upstream end.	Left vane.	Central vane.	Right vane.
Feet.	Feet per second.	Feet per second.	Feet per second.
0	4.86	..	..
24	4.98	..	..
48	5.06	..	..
72	5.06	..	..
96	4.53	5.55	..
120	4.25	5.77	..
144	4.25	6.08	..
168	4.53	4.53	..
192	4.81	3.93	6.00
216	5.06	6.23	5.55
240	5.55	7.87	6.42
264	4.81	5.32	6.42
288	4.81	4.81	6.82
312	4.87	3.93	..

TABLE 51.

Tests on vanes above the Salampur Feeder Ejector.

TWENTY CUBIC FEET OF SAND AND SHINGLE ADDED AT THE HEAD REGULATOR FOR TWO HOURS.

Place of observation.	Silt in cubic feet.
..	17.00
..	1.7
..	.37
..	.20
..	.23

FIG. 51.

MODEL OF KALABAGH WEIR

The subfoundation being a mixture of sand and shingle in the ratio of 1 to 1.

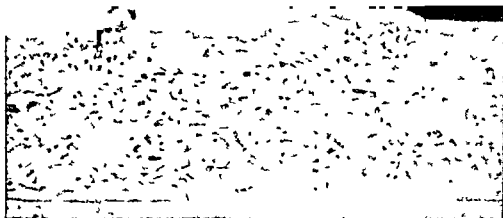
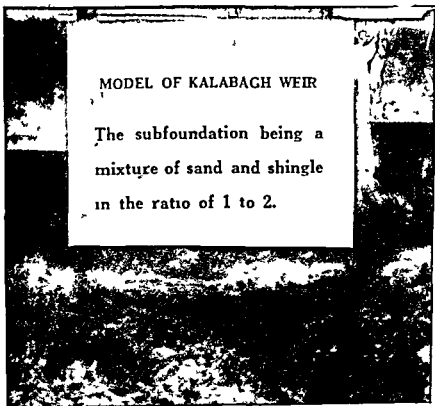


FIG. 51-A.

MODEL OF KALABAGH WEIR

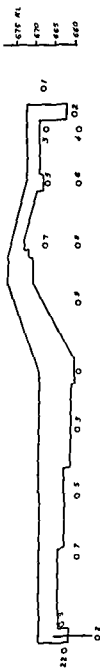
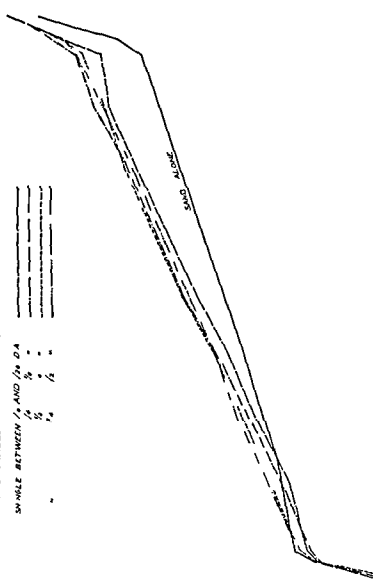
The subfoundation being a mixture of sand and shingle in the ratio of 1 to 2.



MODEL OF KALABAGH WEIR CONSTRUCTED ON A MIXTURE OF SAND AND SHINGLE IN THE RATIO OF 50 50

THE GRADES OF SHINGLE USED ARE

SHINGLE BETWEEN $\frac{1}{8}$ AND $\frac{1}{16}$ DIA	
$\frac{1}{8}$	—
$\frac{3}{16}$	—
$\frac{1}{2}$	—
$\frac{3}{4}$	—



KALABAGH HEADWORKS.
Flow taking place through foundation material.



FIG 56

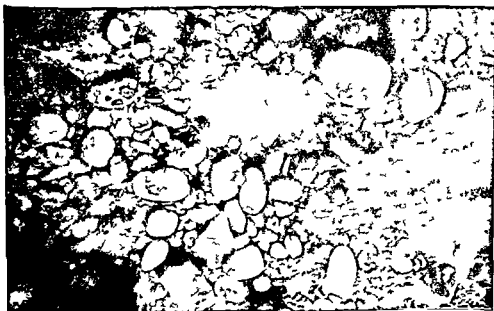
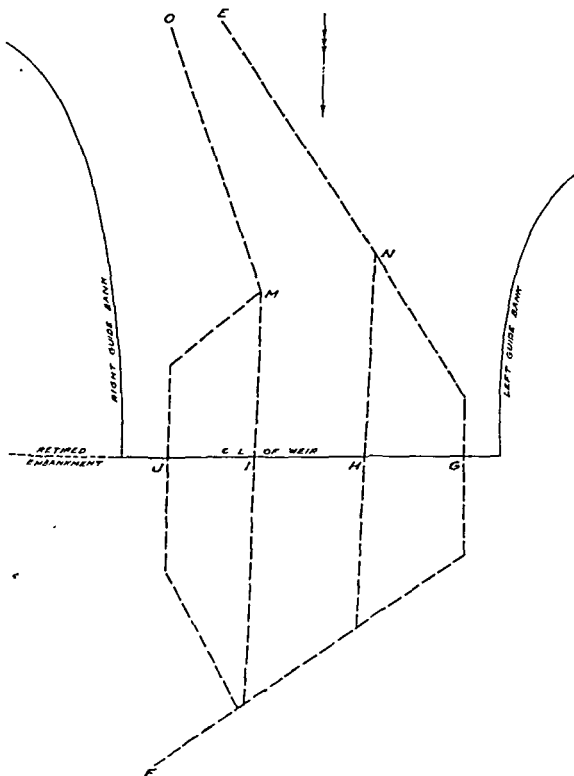


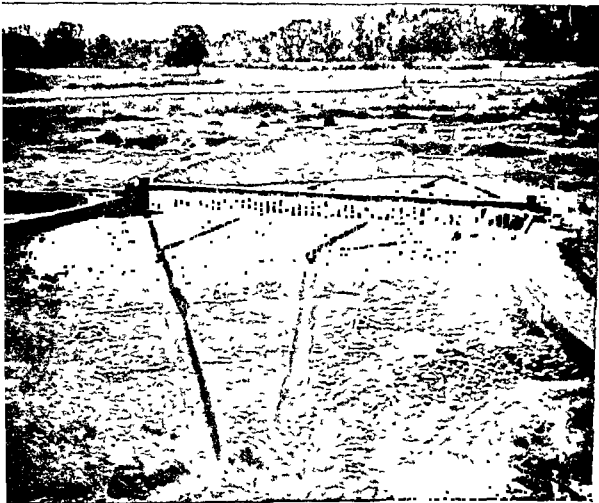
FIG. 57
RIVER INDUS AT KALABAGH WEIR

PROPOSED DIVERSION CUTS (1ST SCHEME) — — — — —



MODEL OF KALABAG'Y HEADWORKS.

FIG. 58.



LOOKING DOWNSTREAM.
Arrangement of diversion cuts.

MODEL OF KALABAGH HEADWORKS.



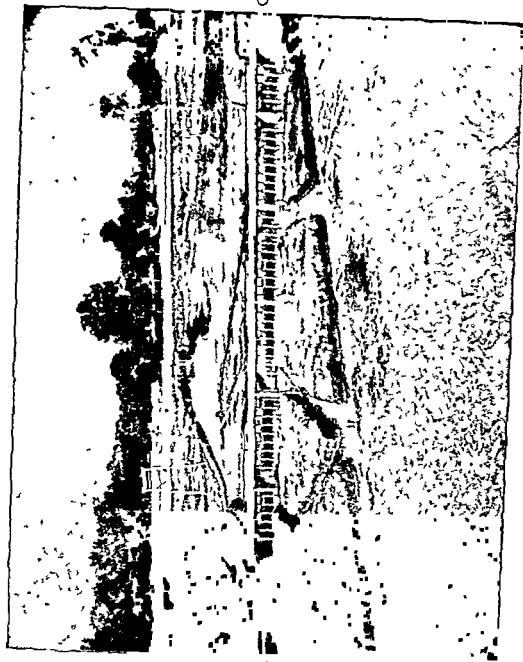
At the commencement of the river diversion.

MODEL OF KALABAGH HEADWORKS.



LOOKING DOWNSTREAM.
Discharge 5,000 cs.

MODEL OF KALABAGH HEADWORKS.



LOOKING UPSTREAM.
Discharge 5,000 cu.

FIG. 61.

MODEL OF KALABAGH HEADWORKS.



MODEL OF KALABAGH HEADWORKS.

FIG. 61-A.



LOOKING UPSTREAM.
Discharge : 7,000 cs.

MODEL OF KALABAGH HEADWORKS.

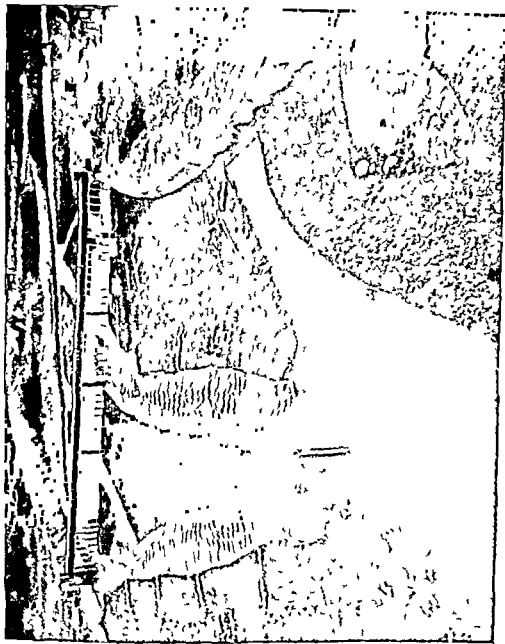


LOOKING DOWNSTREAM.
Discharge : 10,000 cs.



LOOKING DOWNSTREAM.
Discharge : 7,000 cs.

MODEL OF KALABAGH HEADWORKS.

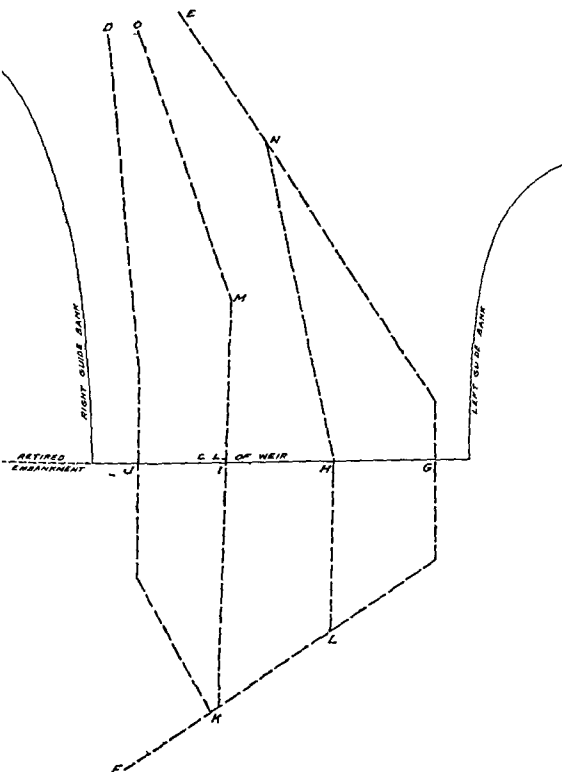


LOOKING DOWNSTREAM.
Discharge : 20,000 cs.

FIG 65

RIVER INDUS AT KALABAGH WEIR

PROPOSED DIVERSION CUTS (2ND SCHEME) ————



MODEL OF KALABAGH HEADWORKS.



Showing position of the cuts.

MODEL OF KALABAGH HEADWORKS.



LOOKING DOWNSTREAM.
Discharge : 5,000 cs.

MODEL OF KALABAGH HEADWORKS.



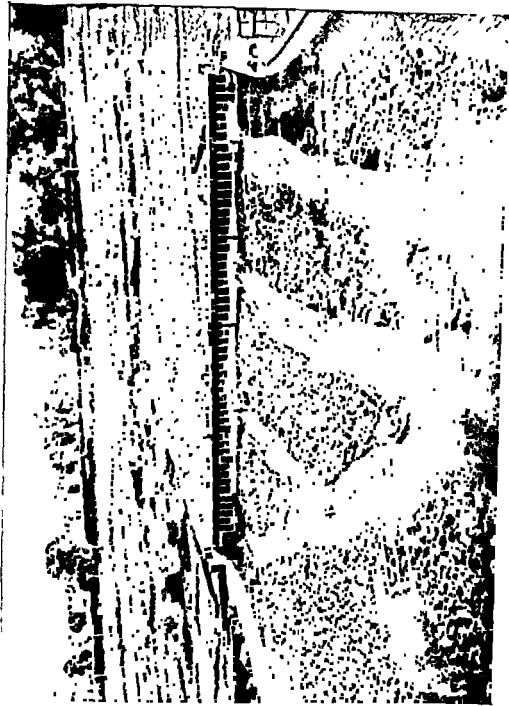
LOOKING DOWNSTREAM.
Discharge : 7,000 cs.

MODEL OF KALABAGH HEADWORKS.



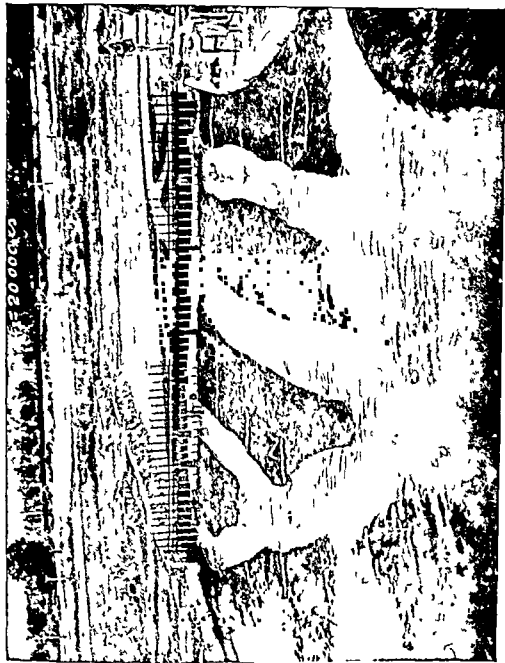
LOOKING DOWNSTREAM.
Discharge : 10,000 cs.

MODEL OF KALABAGH HEADWORKS.



LOOKING DOWN-STREAM.
Discharge : 15,000 cs.

MODEL OF KALABAGH HEADWORKS.



LOOKING DOWNSTREAM
Discharge : 20,000 cfs

MODEL OF KALABAGH HEADWORKS

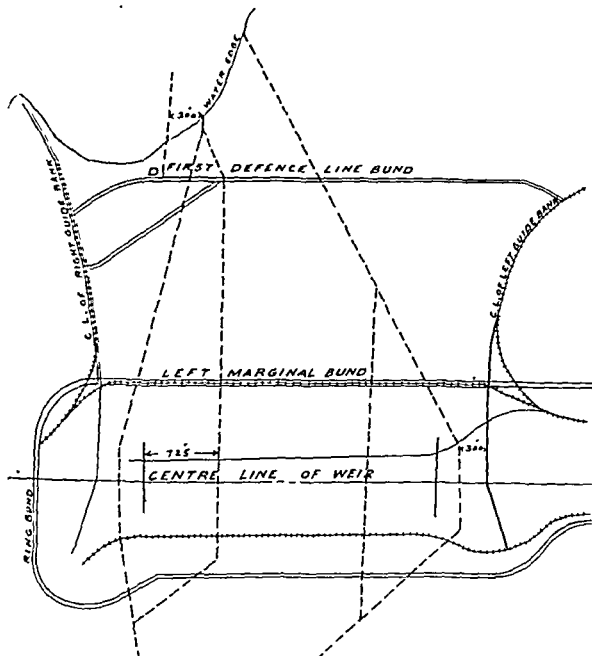


LOOKING DOWNSTREAM
Discharge : 25,000 cs

Fig. 73.

KALABAGH HEADWORKS

PLAN SHOWING POSITION OF PROPOSED DIVERSION CUTS



MODEL OF KALABAGH HEADWORKS.



Showing the diversion cuts as proposed by Mr. F. F. Haigh.



Showing the development of the diversion cuts with the right creek of the river closed.

MODEL OF KALABAGH HEADWORKS



Showing the partial closing of the central creek and the development of the diversion cuts.



Showing the right creek of the river being closed for developing the cuts.

**INDUS RIVER SURVEY PLAN
AT KALABAGH HEADWORKS
SHOWING DIRECTIONS OF FLOW OF BED-WATER**

FIG. 80

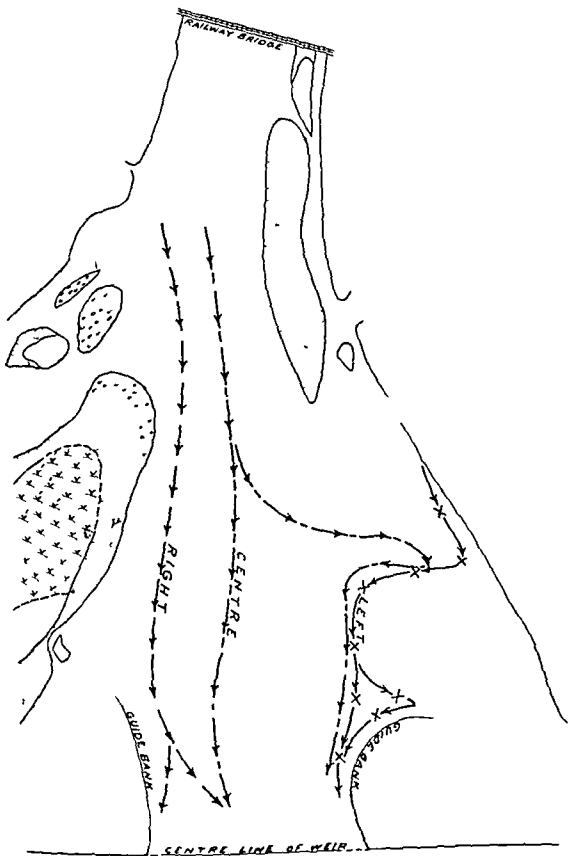
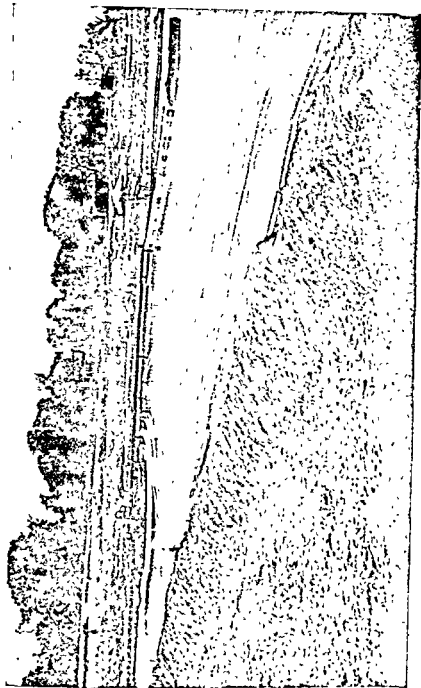


FIG. 81.

MODEL OF KALABAGH HEADWORKS.

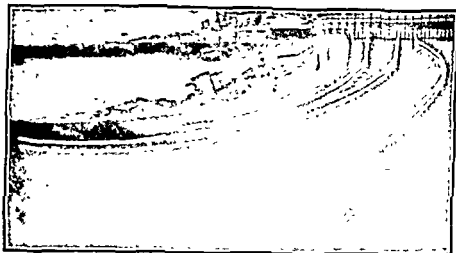


Showing the directions of flow above the weir.

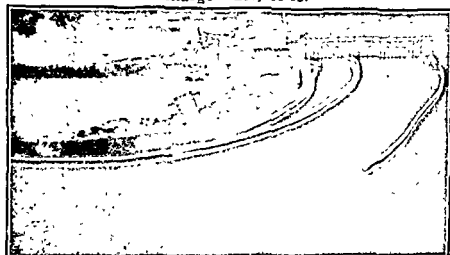
MODEL OF KALABAGH HEADWORKS.

Current directions in the left pocket. Divide wall 300 feet long at fourth pier.

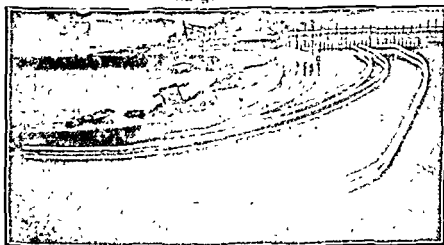
Discharge : 150,000 cs.



Discharge : 200,000 cs.



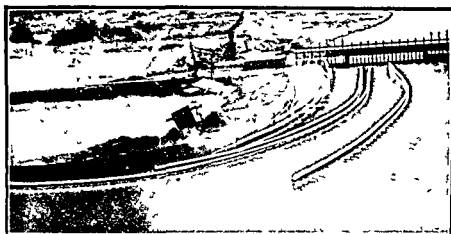
Discharge : 250,000 cs.



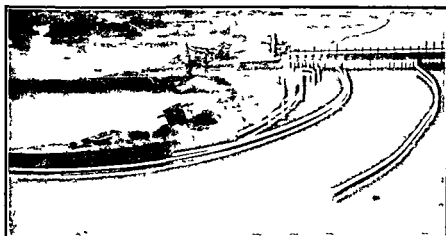
MODEL OF KALABAGH HEADWORKS.

Current directions in the left pocket Divide wall 600'
long at fourth pier.

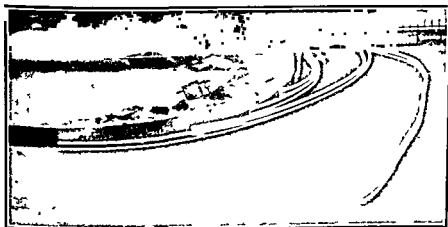
Discharge : 150,000 cusecs.



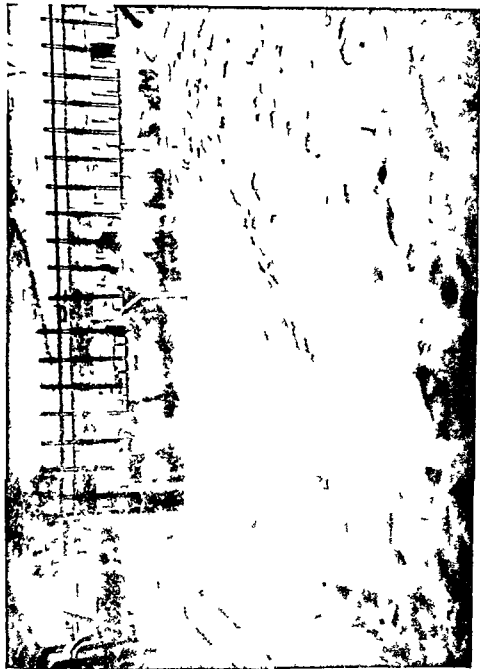
Discharge : 200,000 cusecs



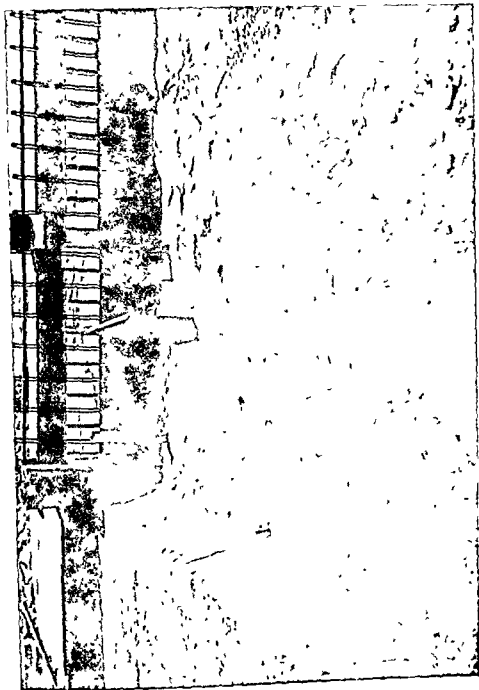
Discharge : 250,000 cusecs



MODEL OF KALABAGH HEADWORKS
Conditions of River Bed with divide wall 300 feet long at seventh pier

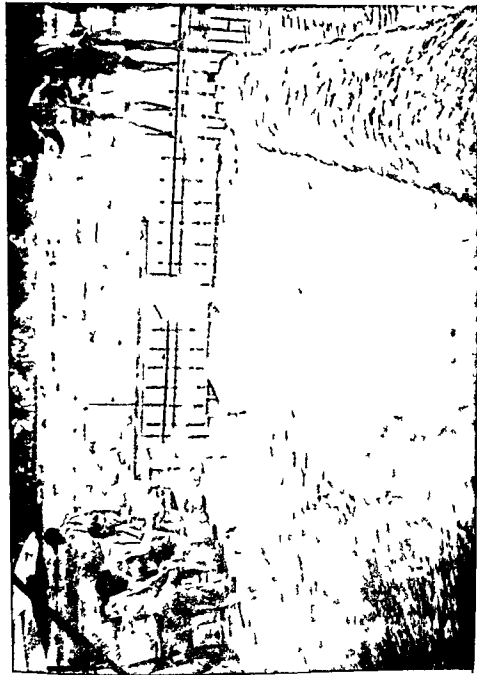


MODEL OF KALABACH HEADWORKS.



Conditions of the River Bed with divide wall 600' long at fourth pier.

MODEL OF KALABAGH HEADWORKS



Showing conditions of flow in the pocket with Kalabagh type of Salt Excluder
 creating 4 underdrains bays and 600' long divide wall at pier No 4 in
 addition to 300' long divide wall at 7th pier.
 A 3,000 cu yd bank at 11th pier of the weir and 40,000 cu yds discharge in the left portion
 of the river

PROPOSED DESIGN
OF
35 COMBINED FALL AND RAPID ON
W J CANAL

FIG 92

LONG SECTION THROUGH FALL



LONG SECTION THROUGH RAPID

FIG. 92a



PLAN

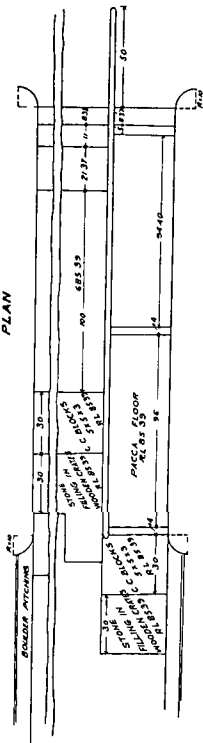


FIG 33
MODELS OF
W.J. CANAL RAPIDS
BED SCOUR
9000 CUSECS
SECTION AT THE END OF PACCA

REFERENCES

- PLAIN RAPID
- FLUMED RAPID DIVERGING SIDES
- FALL OF FALL CUM RAPID
- RAPID OF FALL CUM RAPID
- FLUMED RAPID PARALLEL SIDES

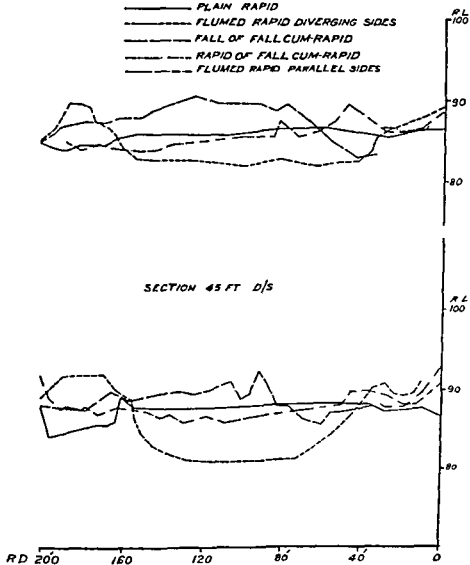
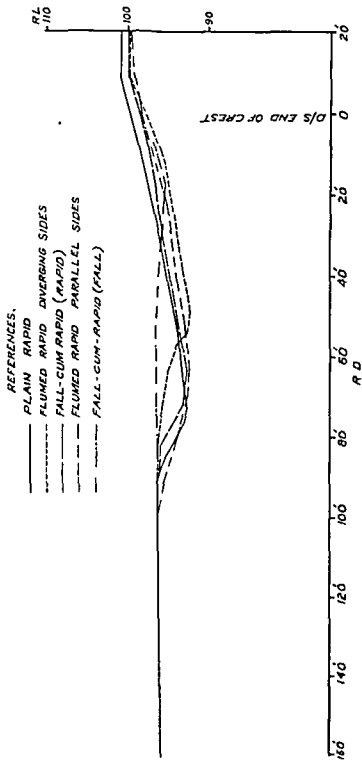


FIG. 94
 MODELS OF
 W.J. CANAL RAPIDS
 WATER SURFACE PROFILE
 9000 CUSECS





PLAIN RAPID
Showing bed scour with a discharge equivalent to 8,000 cusecs

MODEL OF WESTERN JUMNA CANAL RAPID.



PLAIN RAPID

Showing action on the bank with a discharge equivalent to 9,000 cusecs.

MODEL OF WESTERN JUMNA CANAL RAPIDS.



FLUMED RAPID.

Showing action on the banks with a discharge equivalent to 9,000 cusecs.



FALL-CUM-RAPID.
Showing bed scour with a discharge equivalent to 9,000 cusecs.



FALL CUM-RAPIDS

Showing action on the banks with a discharge equivalent to 9,000 cusecs



FLOMED RAPID WITH PARALLEL SIDES
Showing bad scour with a discharge equivalent to 9,000 cusecs



FLUMED RAPID WITH PARALLEL SIDES.
Showing action on the banks with a discharge equivalent to 9,000 cusecs.

FIG. 99
MODELS OF
W J CANAL RAPIDS
BED SCOUR
2000 CUSECS
SECTION AT THE END OF PACCA

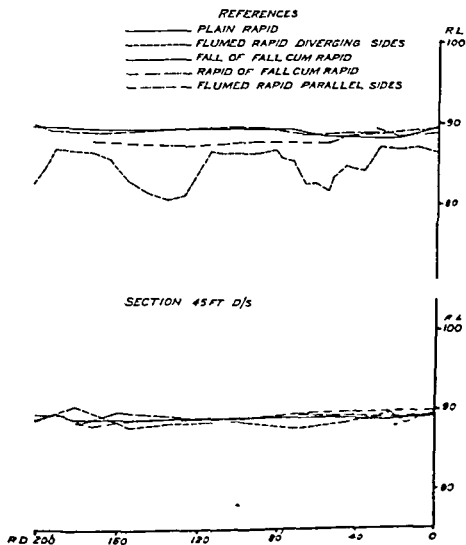
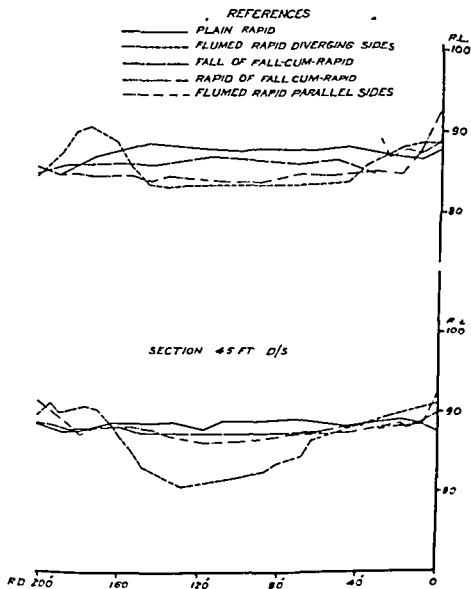
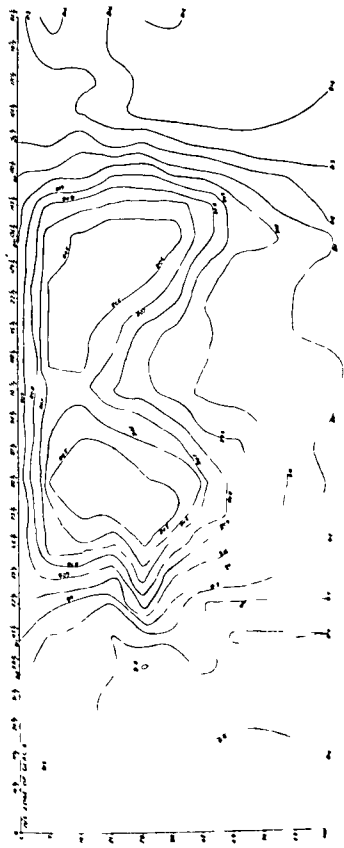


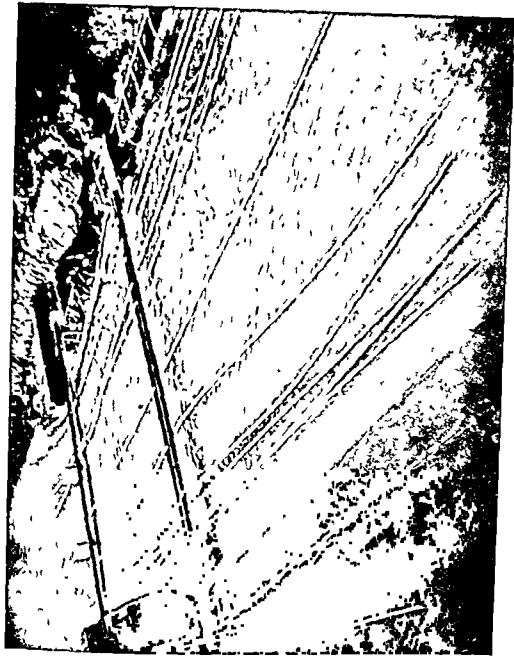
FIG.100
MODELS OF
W.J. CANAL RAPIDS
BED SCOUR
6000 CUSECS
SECTION AT THE END OF PACCA



RALEIGH BRIDGE AT RD 85 SW 3RD BRANCH WESTERN JUNIOR CANAL
 CONTOUR PLAN OF BED BELOW DOWNSTREAM FLOOR WITH THREE FEET BOWING



MODEL OF RAILWAY CROSSING ON WESTERN JUMNA CANAL
FIG. 102.

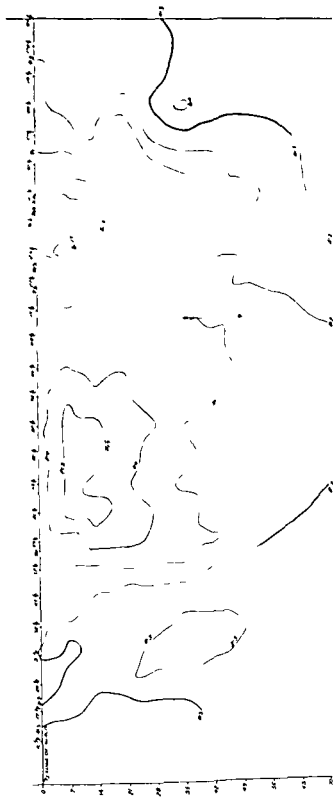


MODEL OF RAILWAY CROSSING ON WESTERN JUMNA CANAL.

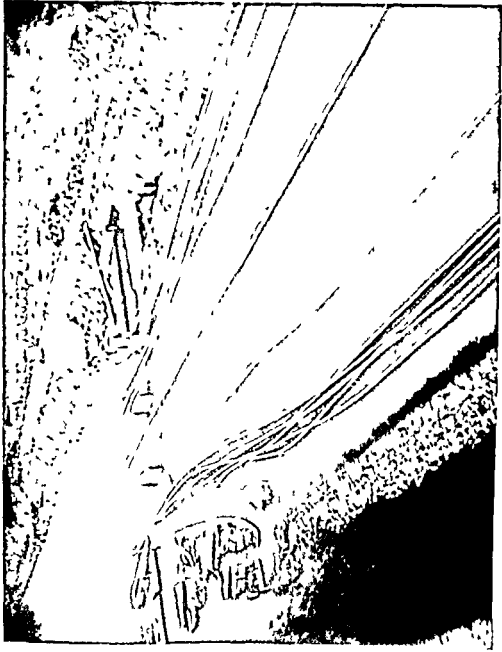


Bed scour with 2' bowing.

ASSESS BRIDGE AT RICE AND MAIN BRANCH WESTERN WILMUNA CANAL
 CONTOUR PLAN OF BED BELOW DOWNSTREAM FLOOD WITH TWO FEET RISING

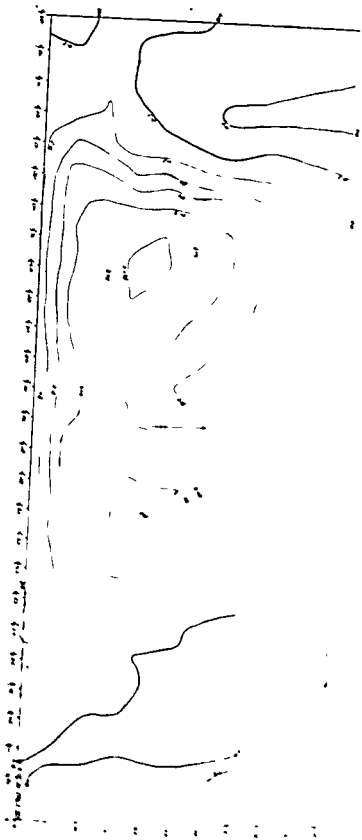


MODEL OF RAILWAY CROSSING ON WESTERN JUNNA CANAL.



Current directions with 2' bowing.

NO 873



SHOULD ALSO SHOW AREA OF RESERVATION AND THE 828 AND 829 RESERVATION
THEY SHOW AREAS FOR FISHING AND 10 OF 10 OF THE FISHING AND 10

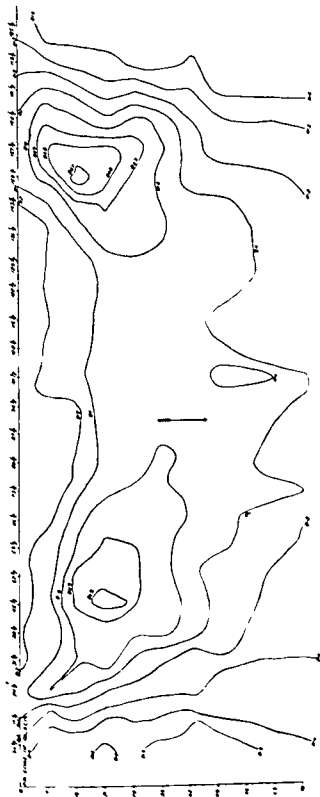
FIG. 107.
MODEL OF RAILWAY CROSSING ON WESTERN JUMNA CANAL.

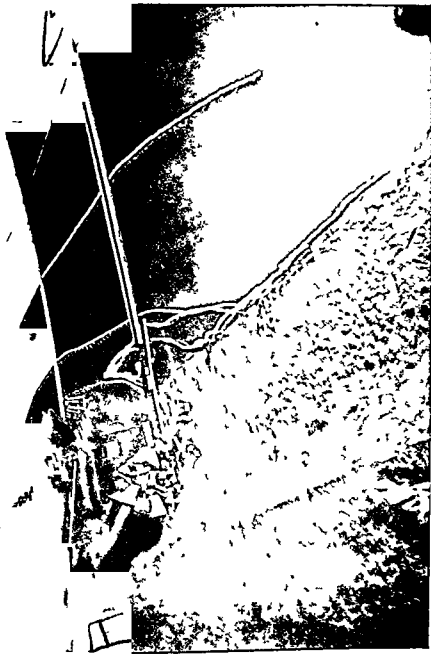


Current direction with 1' bowing

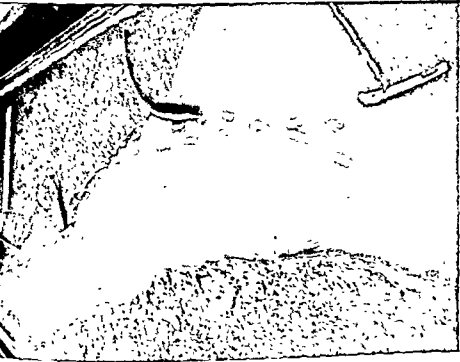
RAILWAY BRIDGE AT R D 65.500 MAIN BRANCH
 CONTOUR MAP OF BED BELOW $\frac{1}{2}$ FLOOD WITH NO BOWING

FIG 100





Current directions with flat floor

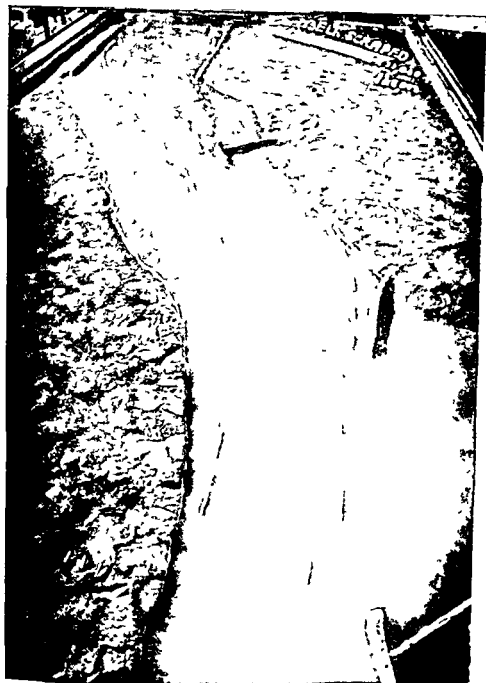


Current directions with the spur in the receded position. There is no concentration of flow at the nose of the spur.

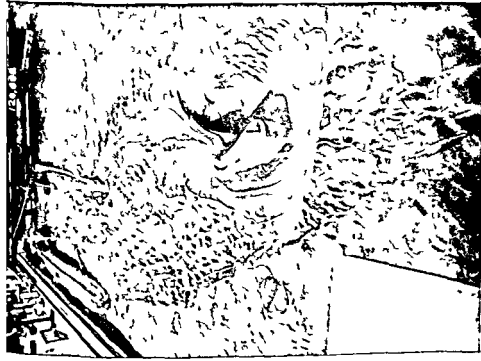


Condition of the river bed with the spur in the receded position. A portion of the subsidiary bela was washed away. Main bela not effected.

FIG. 111.



Showing the current directions with the old spur receded and the bela scraped to R. L. 445.



Conditions of river bed after running a discharge of 120,000 cusecs



Conditions of river bed after running a discharge of 200,000 cusecs

FIG. 113
BED SCRAPED TO R.L. 450

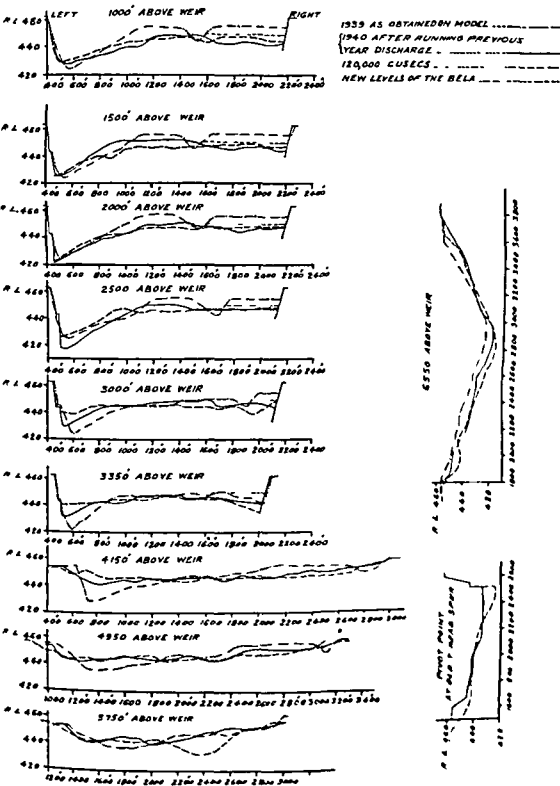
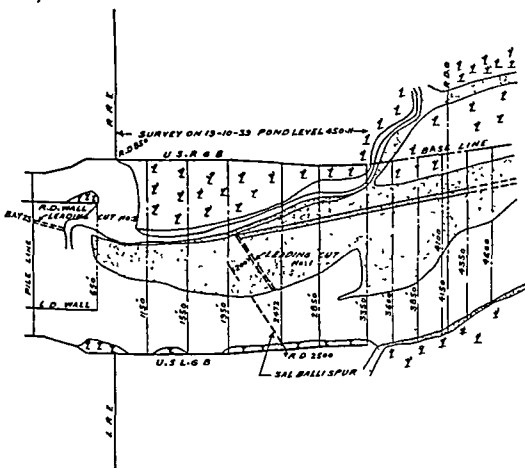


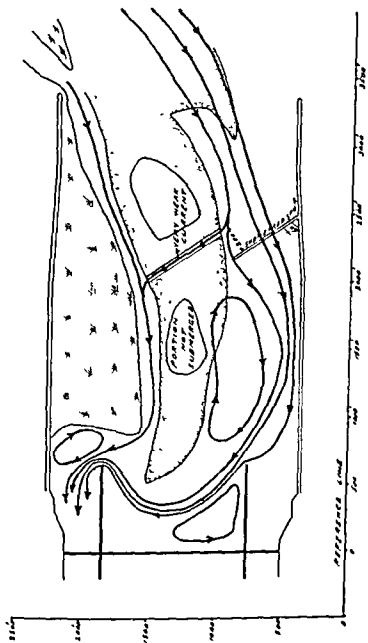
FIG. 114
 ISLAM HEADWORKS
 SURVEY PLAN OF RIVER SUTLEJ



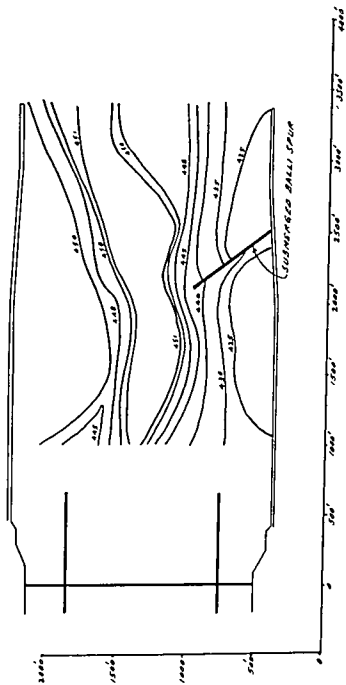


Conditions of the river bed after a discharge of 27,000 cusecs
It will be seen that the cut silts up

MODEL OF
SUTLEJ RIVER ABOVE ISLAM HEAD WORKS
CURRENT DIRECTIONS
DISCHARGE = 27500 CUSECS



MODEL OF
SUTLEJ RIVER ABOVE ISLAM NAG WORMS
AFTER DISCHARGE OF 27000 CUSECS
SUBMERGED SPUR IN POSITION



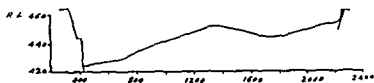
SUBMERGED BALLI SPUR

REFERENCES

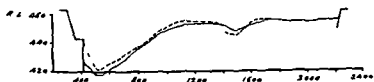
DISCHARGE 27000 CUSECS

1939 AS ATTAINED IN MODEL

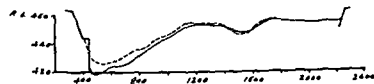
1000' ABOVE WEIR



1500' ABOVE WEIR



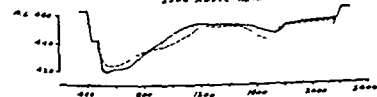
2000' ABOVE WEIR



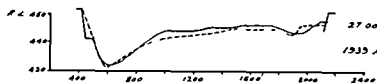
AT SUBMERGED SPUR NOSE



2500' ABOVE WEIR



3000 ABOVE WEIR

REFERENCES

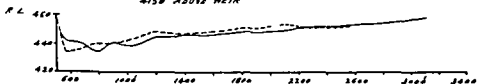
27,000 CUSECS DISCHARGE —

1935 AS ATTAINED IN MODEL - - -

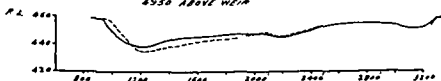
3350 ABOVE WEIR



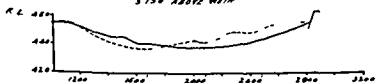
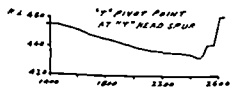
4150 ABOVE WEIR



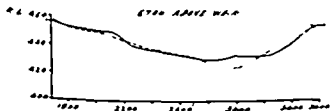
4950 ABOVE WEIR

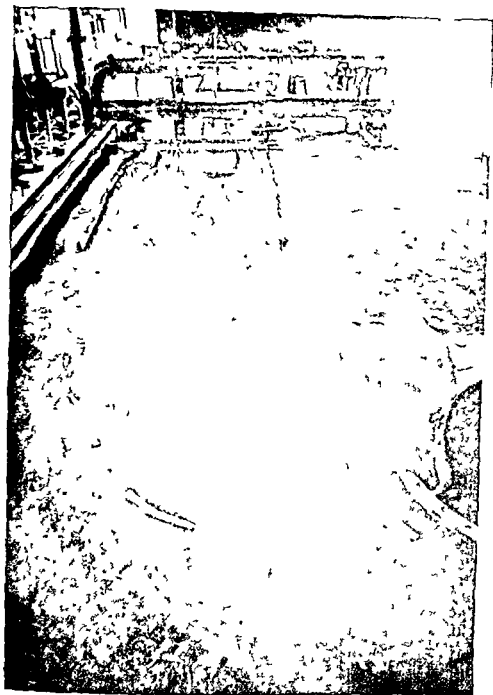


5750 ABOVE WEIR

"Y" PIVOT POINT
AT "Y" HEAD SPUR

6700 ABOVE WEIR





Showing the directions of flow with a discharge of 74,000 cusecs.
 It will be seen that the main attack on the left guide bank is
 at about 1,500' above the weir instead of at 3,000' as it
 occurred last year



Current directions with a discharge of 80,000 cusecs, showing that there is a definite movement of the current from the left towards the centre within the guide banks



Current directions with a discharge of 120,000 cusecs, showing that the current from the old 'T' head spur took a curved course and hit the nose of the right guide bank.

SURNEROFF BRASS SHIPREFERENCES

1935 AT ATTAINMENT MODEL	—————
100,000 CUSECS	-----
120,000 CUSECS	-----
150,000 CUSECS	-----
200,000 CUSECS	-----

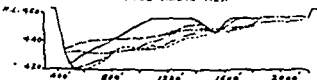
1000' ABOVE WEIR



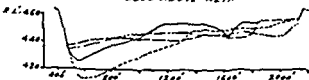
1500' ABOVE WEIR



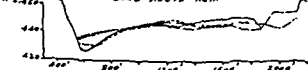
2000' ABOVE WEIR



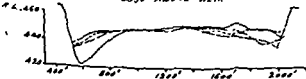
2500' ABOVE WEIR



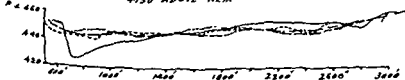
3000' ABOVE WEIR



3500' ABOVE WEIR



4150' ABOVE WEIR





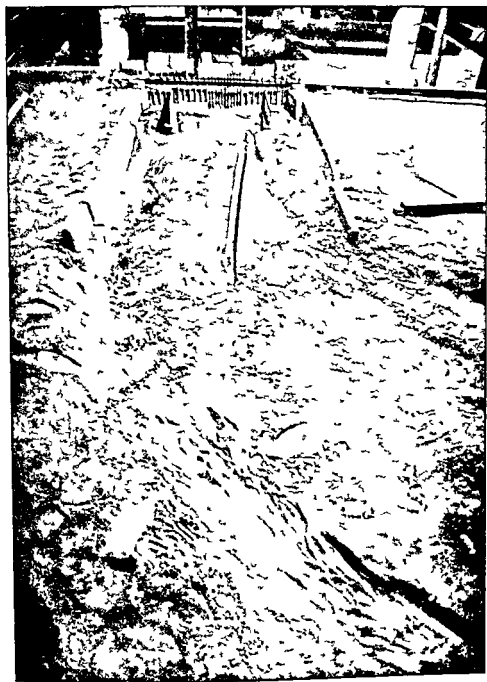
Bed configuration with a discharge of 120,000 cusecs, showing a deep scour hole at the old T head spur.



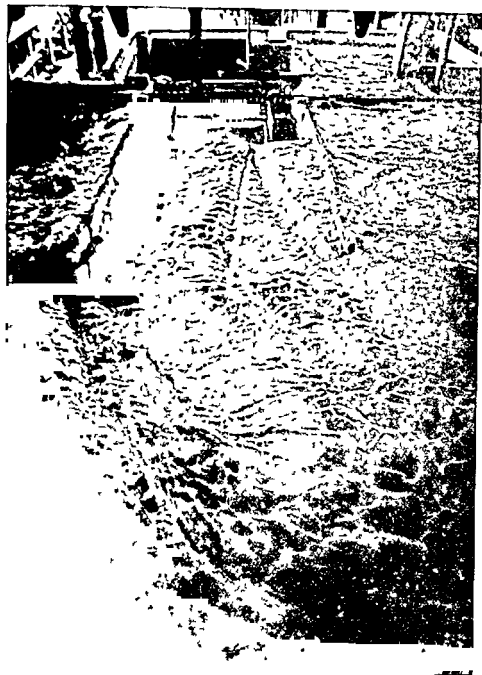
Showing the position of the leading cut in the subsidiary bela.



Showing the conditions of river after running a discharge of 80,000 cusecs. The leading cut shows no tendency to develop



Showing the second leading cut through the subsidiary bela



The cut silts up.

PANUNYAD WEIR MODEL

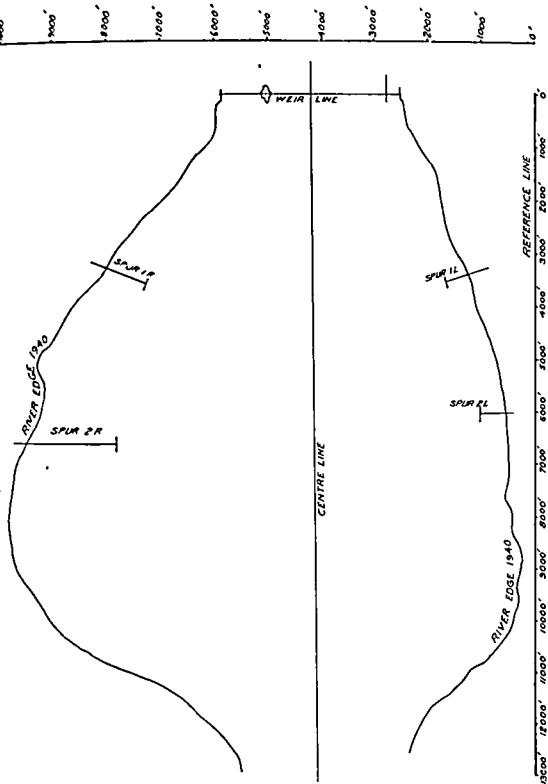


FIG 127-A



Showing the current directions with a discharge of 182,000 cusecs.
The position of the spur is as suggested in 1938

FIG 127 B



Conditions of the river bed after running the model for a period



Showing the current directions with a discharge of 182,000 cusecs, waterway between the spurs 4,500'.



Showig the current directions with a single spur from each side 7,500' below weir
Waterway 4,500'.



Discharge : 182,000 cusecs.



The same as in FIG 129 Discharge: 100,000 cusecs



Showing the conditions of river bed after running it for one season.



Two spurs only, with a leading cut in the Central belt, waterway between the spurs 4,700'. Current directions with a discharge of 182,000 cusecs

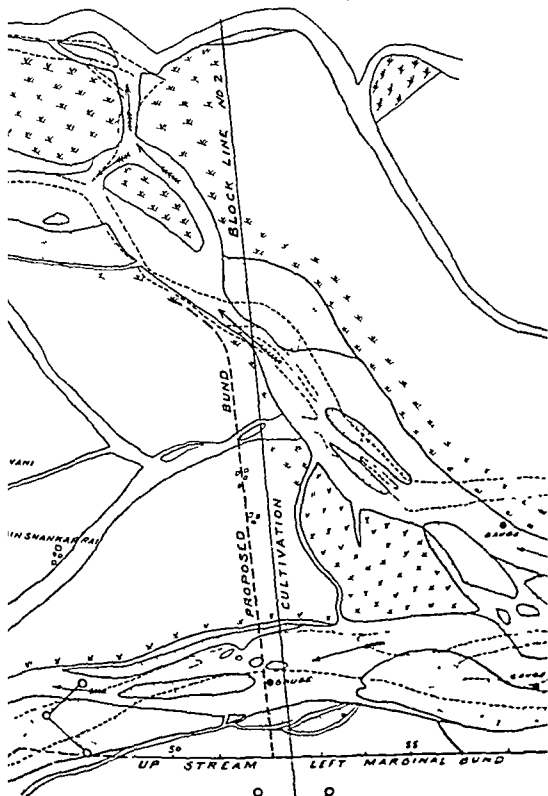
FIG 186





Showing the conditions of the river bed after running season's discharge.

FIG 138



M DEL OF RIVER SUTLEJ ABOVE SULEIMANKI HEADWORKS.



Discharge : 5,000 cusecs.

MODEL OF RIVER SUTLEJ ABOVE SULEIMANKI HEADWORKS



Discharge : 10,000 cusecs



Discharge - 20,000 cusecs.

MODEL OF RIVER SUTLEJ ABOVE SULEIMANKI HEADWORKS



Discharge - 20,000 cusecs



Discharge : 50,000 cusecs.

MODEL OF RIVER SUTLEJ ABOVE SULEIMANKI HEADWORKS.



After the completion of the run

MODEL OF RIVER SUTLEJ ABOVE SULEIMANKI HEADWORKS.



Discharge : 80,000 cusecs.

MODEL OF RIVER SUTLEJ ABOVE SULEIMANKI HEADWORKS.



Discharge : 1,00,000 cusecs.

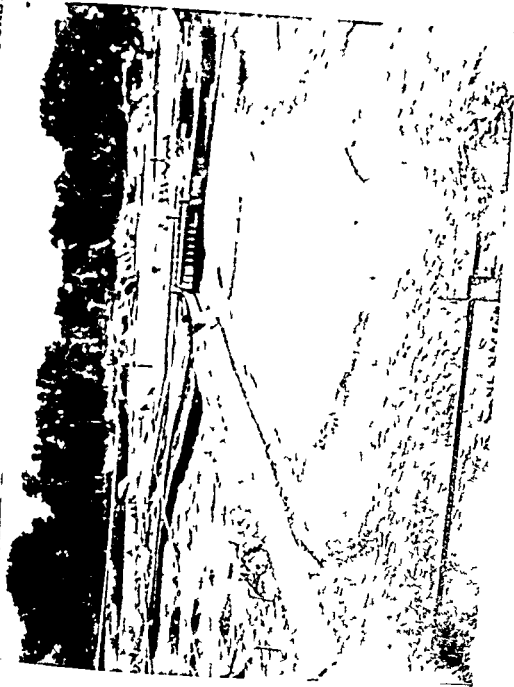
MODEL OF RIVER SUTLEJ ABOVE SULEIMANKI HEADWORKS.

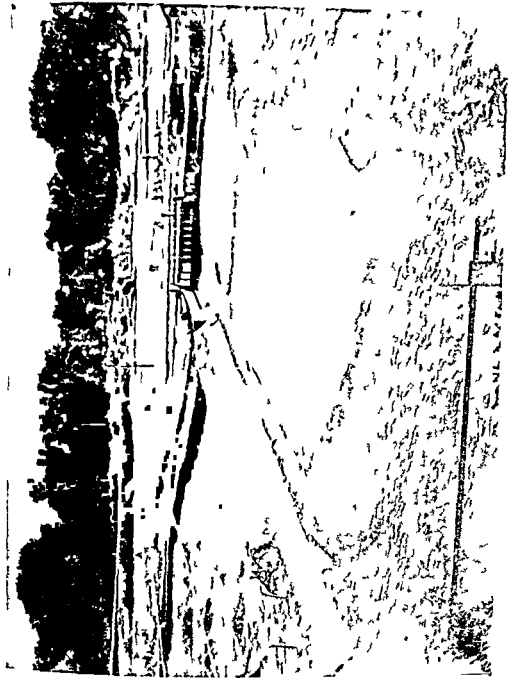


Discharge - 1,50,000 cusecs

MODEL OF MADHOPUR POCKET AND RIVER RAVI UPSTREAM OF THE POCKET.

Fig 119



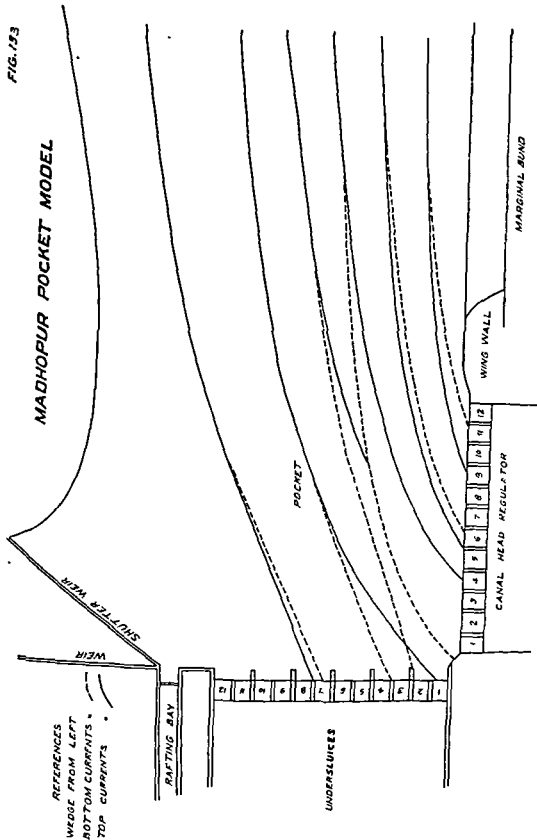


MODEL OF MADHOPUR POCKET AND U B D C MAIN LINE

FIG 149



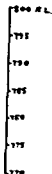
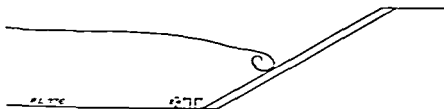
MADHOPUR POCKET MODEL



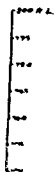
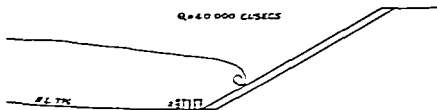
MODEL OF JABA LEVEL CROSSING
GLACIS THICKENED BY 15'

FIG 168

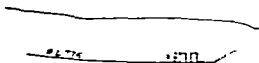
$Q = 56,000$ CUSECS



$Q = 40,000$ CUSECS



$Q = 22,369$ CUSECS



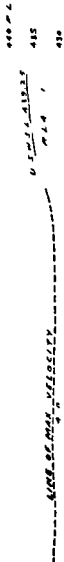


FIG 171

DISCHARGE = 3700 CUSECS

D W 3 L 433.6

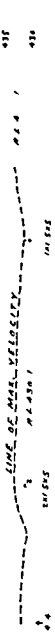


FIG 172

DISCHARGE = 3700 CUSECS

D W 3 L 437.67

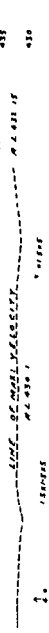
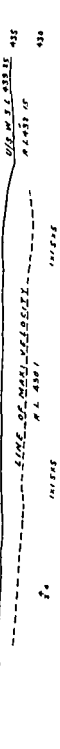


FIG 173

DISCHARGE = 3700 CUSECS

D W 3 L 437.67



DISCHARGE = 3700 CUSECS



MAILSI CANAL FALL AT R.D. 128500

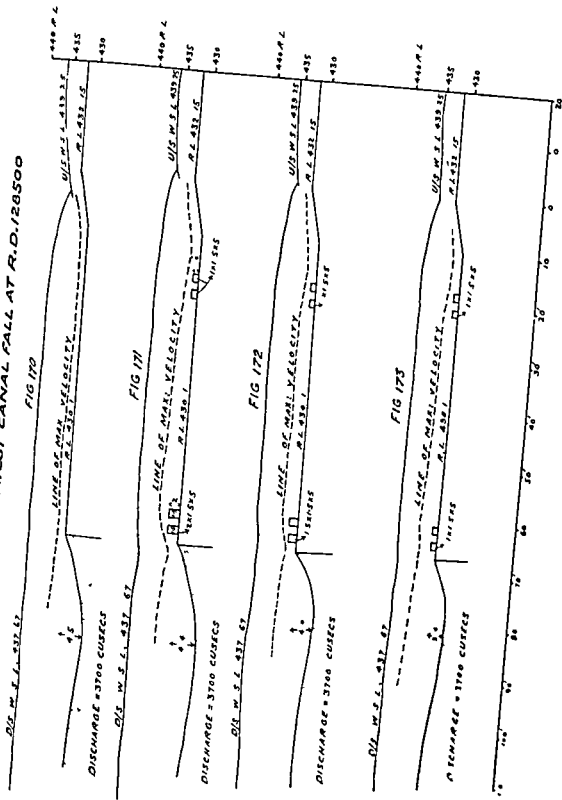
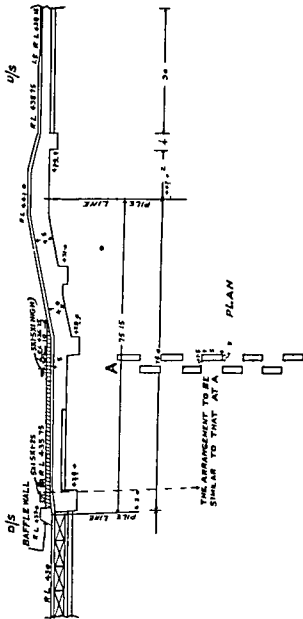


FIG 174 C

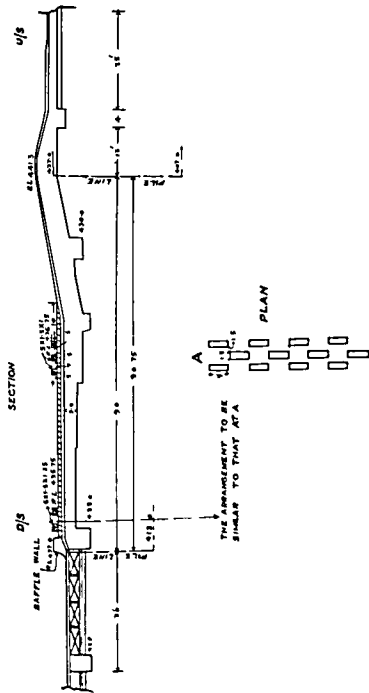
ISLAM WEIR BAYS 5 TO 10

SECTION



ISLAM WEIR

PAGE 26 TO 29



Cropping System 1.

(Cotton/Fallow). Fig. 176.

Mds

Yields of	1937	.	19.9
cotton per	1938	..	18.6
acre.	1939	..	18.3
	1940	.	6.1

The yields of cotton show a distinct decline

In the photograph are seen the patches of thur that have developed. The thur is increasing each year.

*Cropping System 2.*

(Cotton/Berseem). Fig. 177.

11 177

Cotton. Berseem

	Per acre	Per acre
	Mds	Hs
1937	17.5	42
1938	15.9	45
1939	18.7	44
1940	17.0	46

In this case the yields of cotton are normal and do not show any tendency towards decline. Berseem is used in these fields. As the prices of berseem it was the yields are slightly on



In the photograph the crop is healthy and no thur has been seen on the surface.

number of irrigations given to each crop type and the approximate total depth of water is shown in the following table :—

Table.

Crop.	Number of waterings including Rauni.	Approximate total depth of water applied.
		Inches.
Cotton	8	24
Wheat	5	15
Senji	9	27
Berseem	16	48
Rice	37	111

The soil at Jaranwala is very pervious. The high delta under rice is due to the fact that, during the growth of rice, efforts were made to keep water standing in the field. In reclamation practice an allowance of one cusec of extra water for leaching and the growth of rice for an area of 50 acres is made. This works to a delta of six feet approximately.

Before cropping started, a soil profile to a depth of 10 feet was taken from each plot and the distribution of salts and the pH values for each foot depth determined. The depth of the water-table was also recorded at a number of points. The average depth of the water-table in the area was 17 feet.

After three years' cropping, the results of the various cropping systems have now become apparent, though the detailed analyses have not yet been completed. As the results are of considerable importance both with reference to reclamation and deterioration and to project development an account of this will be given. As the analyses have not been completed, the account will be illustrated by photographs of the condition of each plot in January, 1941.

Cropping System 1.

(Cotton/Fallow). Fig. 176.

Mds.

Yields of	1937	..	19.9
cotton per	1938	..	18.6
acre.	1939	..	18.8
	1940	..	6.1

The yields of cotton show a distinct decline.

In the photograph are seen the patches of thur that have developed. The thur is increasing each year.

*Cropping System 2.*

(Cotton/Berseem). Fig. 177.

1 177

Cotton. Berseem

Per acre. Per acre

Mds. Rs.

1937	..	17.5	12
1938	..	15.9	15
1939	..	18.7	11
1940	..	17.0	48

In this case the yields of cotton are above normal and do not show any tendency towards decline. Berseem is used in these fields. As the prices of berseem at present the yields are slightly on increase.

In the photograph the crop is generally good and no thur has appeared on the surface.



(Cotton Senji) Fig 178.

Cotton Senji

Mds
Per acre

14 2	Good
13 5	Fair.
13 5	Fair
6 1	Poor.



Cotton is a light irrigation crop ;
In spite of the fact
that and rain crops are
grown in this field there
have started appearing.
yields of crops are declin

Cropping System 4.

(Wheat/Wheat) Fig. 179.

Wheat.

Mds
Per acre.

32 6
25 6
22 0



Cropping System 5.

(Fallow/Senji). Fig. 180.

Fig. 180

		<i>Senji.</i>
1937 ..	.	Good.
1938 ..		Good.
1939 ..	..	Fair.
1940 ..	..	Poor.

Patches of thur are visible in the photograph. The condition of crop as noted in the Crop Register also indicates deterioration.



Cropping System 6

(Fallow/Bersum) Fig. 181.

Fig. 181



Berseem

Per acre.

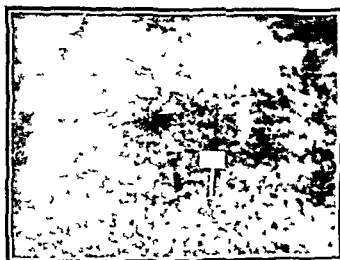
Rs

24

61

61

67



land has improved con
 s The price of ber eem
 is increasing In a por
 field cotton was intro
 two rice crops The
 American cotton were in
 bourhood of 17 maunds

The importance of the conclusions is shown by the area to which the results apply.

2. *Chak 188-N. B., Lower Jhelum Canal.*—The results obtained at the experimental farm in Chak 188-N. B. have been discussed in the previous reports. The importance of this area is that it indicates the permanency of reclamation when certain standards of culture have been adopted. A summary of the work done on the farm is given below.

The average yields of crops from the reclaimed area are :—

Rabi 1935-36.

Maunds.

Wheat	..	14.0	
Gram	..	17.0	
Berseem	..	612	(fodder).
Turnips	..	240	„
Senji		160	„

Kharif 1936.

Maunds.

Cotton	..	11.5	
Sugarcane	..	76	(Gur).
Guara	..	190	
Chari-guara		340	

Rabi 1936-37.

Maunds.

Wheat	..	15.5	
Turnips	..	160	(fodder).
Toria	..	10.5	
Berseem	..	880	(fodder).

Kharif 1937.

Maunds.

Cotton	..	10.2	
Chari-guara	..	320	(green fodder).

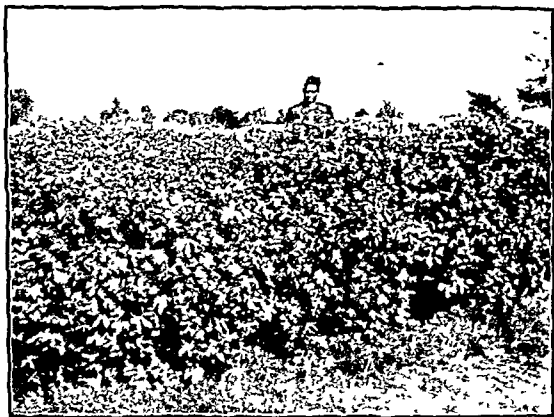
Rs.

Sugarcane sold at	..	240	per acre.
Maize sold at	..	64	per acre.

Rabi 1937-38.

Maunds.

Wheat	..	18.7	(1.32 acres sold for fodder at Rs. 89 per acre).
Berseem	..	882	(green fodder).
Toria	..	10.4	
Gram	..	6.5	(Low yield due to attack of gram blight).
Sugarcane	..	..	(Sold at Rs. 240 per acre).



The soils of the area have been examined. The results of analysis show that both the salt content and the pH values are low throughout the depth of the soil profile. This shows that there is no tendency for the salts to accumulate at the surface. The reclaimed land has been given on lease. Although the highest offer was a rate of Rs. 15 per acre it was considered advisable to give it to the same tenant who was responsible for its cultivation during and since the period of reclamation so that the same standard of agriculture might be maintained. To this tenant, the land has been leased at Rs. 9 per acre.

<i>Kharif 1938.</i>		
Cotton	..	12.8 Mds.
Sugarcane	.. ..	(Sold at Rs. 120 per acre for seed).
Maize	.. ..	(Sold as green fodder at Rs. 88 per acre).

<i>Kharif 1939.</i>		
	Maunds.	
Cotton	..	8.6
Toria	..	16.8
Maize	..	Sold at Rs. 80 per acre.
Sugarcane	..	56 (Gur).
	..	1½ kanāl sold at Rs. 180 per acre for seed.

<i>Rabi 1939-40.</i>		
	Maunds.	
Wheat	..	25.5
Gram	..	9.8
Toria	..	16.8
Turnips	..	480 (green fodder) sold at Rs. 48 per acre.
Oats	Sold at Rs. 80 per acre as green fodder.

<i>Kharif 1940.</i>		
Cotton	.. ..	Average so far 9.8 maunds (Picking not yet finished).
Sugarcane	.. ..	Condition very good.

Figs. 184, 185 and 186 illustrate the type of land before reclamation, the condition of crops obtained during reclamation and the condition of cotton during kharif 1938, i.e., seven years after reclamation.

Reclamation of thur land on big estates and on small holdings—Reclamation of thur land is being carried out by big landlords on contract supplies of water and by small zemindars on supplies assessed under a special schedule. Fig. 187 is a map of the canal irrigated tracts of the Punjab in which localities where reclamation was in progress during 1940 are marked.

Sukheki-cum-Sangla Centre—The experiment on an area of 500 acres, the description of which was given in the annual report for the year ending April, 1940, was continued. During Rabi 1939-40 approximately 250 acres were put under crops as shown below.—

Crop				Area sown.
				Acres.
Berseem	..	..	..	125
Wheat	..	.	..	108
Gram	..	.	..	19

The wheat was sown in the area which carried an early crop of rice and in which a leguminous crop of San for green manuring was sown after rice.

Gram was grown in the wadh watta of rice and was matured without any irrigation during the Rabi. Berseem was given the normal number of waterings during the winter. The average yields of crops sown during Rabi 1939-40 are given below.—

Name of crop	Average yield per acre	Maximum yield per acre
	Maunds	Maunds
Wheat	12 8	22 0
Gram	15 0	27 0
Berseem	262 0 of green fodder	800 0

Regarding berseem, since the zemindars were required to sow this after rice they reduced the area under fodder in their undeteriorated holdings and sowed wheat instead. Any crop that was left over and above the zemindar's own requirements for his cattle was sold by him at an average rate of Rs. 8 per kanal. In preparing costing accounts, therefore, berseem has been valued at Rs. 8 per kanal.

The success of gram on the wadh-wattar of rice at Sukheki and in areas under reclamation on the Lower Bari Doab Canal has solved the zemindar's difficulty of making available rabi supplies of water for leguminous crops following rice. In addition, it has been shown that it is possible to complete the process of reclamation even on kharif channels where rabi supplies of water are not available. A successful crop of barani gram increases the profits on reclamation.

Judged from the growth of rice and the following crops of berseem or gram and also from the analyses of soils, 81 acres were considered fit for normal cropping during kharif 1940. The following crops were sown:—

Name of crop.			Variety.	Area sown.
				Acres.
Cotton	..	..	<i>Desi mollisoni</i>	28.0
			39	
			American L. S. S.	38.0
Sugarcane	..	..	..	6.5
Podders	..	..	..	8.0

The remaining area was put under rice again.

Cotton.—Desi cotton was sown in an area of 28 acres. No manure was applied. It made excellent growth and gave an average yield of 13.0 maunds per acre, the maximum being as high as 24.0 maunds. Fig. 188 shows the size of the plants after picking cotton.

The American variety was sown in an area of 38 acres and has given an average yield of 11.5 maunds per acre, the maximum being 15.5 maunds. Fig. 189 shows a field of American cotton in reclaimed land.

Sugarcane.—The whole of the crop was not harvested as a large portion of it had to be sown for seed. The price obtained was Rs. 120 per acre approximately. From the crushings made, an average yield of 40 to 50 maunds of gur per acre was obtained. The sugarcane in reclaimed fields was sown after a leguminous crop following rice and received no farmyard manure. Fig. 190 shows the condition of land before reclamation and Fig. 191 shows the same land after reclamation when sugarcane followed rice and berseem. Fig. 192 shows the comparison between the condition of the sugarcane crop in reclaimed land and that in the adjoining undeteriorated field which had been previously manured with farmyard manure.

During kharif 1910 the Sukheki area was converted into a centre. With Secretary to Government, Punjab, Public Works Department, Irrigation Branch, letter No. 981-S./Rev., dated 30th May, 1910, the following schedule for assessment of small holdings which are included in a reclamation centre was sanctioned:—

Classification.	Good area in the holding which can produce better than a four anna crop.	Land revenue to be charged per acre matured under reclamation.	WATER RATES.	
			OCCUPIERS' RATE TO BE CHARGED PER ACRE MATURED UNDER RECLAMATION.	
			Rice.	Kharif fodder crops.
	Acres.	Rs. A. P.	Rs. A. P.	Rs. A. P.
A	0—12½	..	..	..
B	12½—18½	0 8 0	1 10 0	0 10 0
C	18½—50	1 0 0	3 4 0	1 4 0
D	50—75	1 8 0	4 14 0	1 14 0
E	75 and above	2 0 0	6 8 0	2 8 0

The water rates are, therefore, graded at $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$ and full schedule rates as specified above.

NOTE.—(i) On Rabi crops grown in areas under reclamation land revenue shall be charged at a special rate of Rs. 2 per acre.

(ii) The concession rates shall only apply to the fields in the estate in which land reclamation work by the Department is in progress.

(iii) In cases of areas under reclamation, full remission of occupiers' rates will be given if the crop is less than eight annas as ascertained after actual weighing.

(iv) For the Rabi crops grown in areas under reclamation, full schedule rates will be charged but full remission will be given if the crop is less than eight annas.

(v) The rate charged on each field will be fixed in accordance with the acreage still capable of giving crops held by the owner or owners of a holding in the same village irrespective of whether actual cultivation is done by the owner himself, a tenant or a mortgagee where land is in possession of a mortgagee.

As orders for opening the centre were received late and the provision of the extra water supply took another month, rice cultivation did not start till the end of July or the beginning of August. Leaching was insufficient and the yields were, therefore, low. Under the new schedule, reclamation was in progress in Chaks 110, 111, 116, 117, 118, 119, 120 and 96-R. B. on Dabora, Gilluana, and Morauwala distributaries, all in Sheikhupura district. Further areas in Chaks 112, 113, 114 and 115-R. B. in which reclamation was in progress free of assessment were brought under reclamation and were assessed according to the schedule rates. The total reclamation area under rice during kharif 1910 was 1,011 acres.

Costing accounts for kharif 1939 were given in the annual report for the year 1940. These were continued during Rabi, 1939-40. A summary of the accounts both for kharif 1939 and rabi 1939-40 is given in Table 52. Out of the total profit a sum of Rs. 4,694 has been deducted on account of the land revenue and water-rate which would have been levied according to the new schedule had the area been included for assessment. The average net profit to the zemindar after one kharif and one Rabi crop comes to Rs. 36 per acre. This is evidenced by the fact that almost all arrears of land revenue and water-rates have been paid by zemindars, new houses have been built and new cattle have been purchased by those whose lands have been reclaimed. Several zemindars have paid back their debts.

It is evident from the above remarks on the zemindars condition in the Sukheki area, that financially they are now much better off and likely to be more contented.

During rabi 1940-41 the following crops have been sown:—

Name of crop.				Area sown.
				Acres.
Gram on wadh watter	..	..	..	41.5
Wheat after an application of farmyard manure..				151.0
Berseem	..	..	..	309.0

The germination and growth of the rabi crops is good. It is expected that the yields will be above normal.

A further experience gained in the reclamation of the Sukheki area indicates that the zemindars are willing to pay land revenue and water rates on the deteriorated area according to the schedule sanctioned by Government.

A soil survey of the areas under reclamation in the Sukheki-cum-Sangla Centre is in progress. It is anticipated that in approximately 500 acres the salt content and alkalinity have been reduced to the figure considered satisfactory for normal cropping. In the reclaimed area cotton, sugarcane and kharif fodders will be sown during kharif, 1941.

Two new centres of reclamation have been sanctioned. One of these centres is situated in the Dangali tract where a large area has become *thur* and rapid deterioration is in progress. The second centre is situated in the Nankana Sahib area where again land is going out of cultivation at a very rapid rate. The two new centres have been opened in areas where land has recently gone out of cultivation. From the experience of reclamation on contract supply of water in Chak 236-G. B., belonging to Raja Sir Daya Kishen Kaul it is expected that the reclamation will be complete in two kharif seasons.

RECLAMATION OF LAND ON CONTRACT WATER SUPPLIES.

Lower Bari Doab Canal.

Renala Estate.—The work on the reclamation of land in Renala Estate has been described in the reports for the year 1939 and 1940. The land in the Renala Estate was classified as first class when colonisation started. Deterioration due to the upward movement of salt started in the year 1931 but as the damage was insignificant no serious notice was taken. A survey was carried out in 1937 by the revenue staff of the Irrigation Department and it was discovered that *thur* was increasing in the estate at a rapid rate. The survey was repeated under the supervision of the Irrigation Research Institute in January, 1939 and again in March, 1940. From the results of these surveys it is now known that out of the total area approximately 1,300 acres has become *thur* and that the annual deterioration varies between 300 and 400 acres. A summary of the results of reclamation so far achieved is given below :—

Name of crop.	Area sown. .. Acres.	Average yield per acre.	REMARKS.
---------------	-------------------------	-------------------------	----------

KHARIF, 1938.

Rice	50.0	7.0 maunds	..	Low yield is due to reclamation having been taken up late in the season.
------	-------	------	------------	----	--

RABI, 1938-39.

Barseem	50.0	..		Sold Green.
---------	-------	------	----	--	-------------

KHARIF, 1939.

Rice	.. ..	23.0	..		Early variety of rice gave an average yield of 18 maunds per acre. The late varieties were attacked by the rice borer.
Cotton	.. ..	5.0	10.4 maunds	..	Cotton sown in the reclaimed area was free from the attack of tirak, whereas that sown in the undeteriorated land in the estate was attacked by tirak.

him and rice was sown in an area of 23 acres. After rice the following crops have been sown:—

				Acres.
Gram	..	..	..	14
Berseem	..	..	..	4
Wheat	..	..	..	0.5

Chak 25/11-L.—(belonging to R. S. Ch. Bahadur Chand).

In this chak the water-table is deep, about 40 feet from the natural surface. During 1939 R. S. Ch. Bahadur Chand informed the Chief Engineer that his lands were deteriorating on account of *thur* and that a considerable portion of the area had gone out of cultivation. The matter was investigated and it was found that the statements made by the Rai Sahib were supported by the records of the civil patwari. One cusec of extra water was sanctioned for reclamation in this area during kharif, 1940. Approximately 42 acres of rice were sown which gave an average yield of 16 maunds per acre. After rice the following crops have been sown:—

				Acres.
Gram	..	..	..	16
Berseem	..	..	..	16

The condition of the rabi crops is satisfactory.

Chak 126/15-L.—(belonging to S. B. Ujjal Singh, M.L.A.).

The whole of this chak is of the bara type. The Sardar Bahadur had been attempting reclamation of the area by the addition of silt. This had not been successful as indicated by crop yields. Cotton in the area is almost always attacked by *tirak*. The whole of the water-supply allotted for the village has been utilised in the portion that has been improved by the addition of silt. The Sardar Bahadur obtained two cusecs of water for reclamation on a contract basis with effect from kharif, 1940. Fields which had received no dressing of silt were selected for reclamation. A soil survey was made which showed that the area was alkaline and had reached the *Rakkar* stage. The Sardar Bahadur was informed that reclamation could not be completed with less than three rice crops. The Sardar Bahadur agreed. During kharif, 1940, 101.5 acres of rice were sown. Although rice had not been a complete success, the Sardar Bahadur's tenants requested him to give that area to them on lease during the rabi season. Instead of giving land to the tenants, the landlord has sown under direct cultivation, gram in 27 acres and berseem in 23 acres. From a report by the Sardar Bahadur berseem is likely to sell at Rs. 50 per acre. It is proposed to continue rice in the same area during kharif, 1941. In addition a further supply of 6 cusecs has been sanctioned as the area proposed for reclamation is 1,200 acres approximately.

B. C. G. A. (Khanewal).—Complaints had been made that in spite of good cultivation at this farm the yields of crops particularly

of cotton had declined from an average of 16 maunds of cotton to between 3 to 4 maunds. Patches of *thur* had started appearing in cotton fields and it was stated that *thur* was on the increase. At the request of Sir William Roberts a visit was paid to the estate and a soil survey was carried out. It was found that salts were present in the soil crust in the majority of the profiles and that the salt in the soil crust was responsible for the appearance of *thur* at the surface. At the request of B. G. G. A. five cusecs of extra water was sanctioned by the Chief Engineer to start experiments:—

- (a) to prevent the upward movement of the zone of accumulation of salt;
- (b) to depress this zone to a depth of more than 6 feet so that yields of cotton and other crops may improve;
- (c) reclamation of *thur* land where the zone of accumulation had reached the surface.

During kharif, 1940, 183 acres of rice were sown which gave an average yield of 13 maunds per acre. After rice gram has been sown in 68 acres on wadh-wattar; berseem in 49 acres under rabi irrigation and wheat in 15 acres after an application of farmyard manure. The germination of the rabi crops is good. A soil survey is in progress to determine the salt content and the alkalinity in the soil profile to enable fields to be selected for cotton and sugarcane for kharif, 1941. During kharif, 1941, reclamation will be restricted to an extra supply of three cusecs only.

Costing accounts are being maintained for all areas on contract supplies of water. As the system of cultivation and the terms with the tenants differ with different landlords in different localities, the costs vary in each case. This is the first year of reclamation on contract supplies in the Lower Bari Doab Canal. Costs have not been given in this report as, from the soil surveys, it seems that the areas are only partially reclaimed and that rice should be sown again in kharif, 1941. This aspect will be dealt with in the report for the year 1942.

Lower Chenab Canal.

On the Lower Chenab Canal extra water for reclamation had been obtained by Pir Diwan Ali; Raja Narindra Nath; Raja Sir Daya Kishan Kaul and Gurdwara Nankana Sahib. The chaks belonging to these landlords are situated in the region where rapid deterioration is taking place.

Kot Diwan Ali.—This chak belongs to Pir Diwan Ali Shah and almost the entire chak has become *thur* so much so that the majority of the tenants had left the place and the village was more or less deserted. An extra supply of 1.5 cusecs was sanctioned and reclamation was started in kharif, 1940. A trained Village Assistant was posted to supervise the reclamation operations. A total area of 125.5 acres was sown under rice. This gave an average yield of 14 maunds

him and rice was sown in an area of 23 acres. After rice the following crops have been sown:—

	Acres.
Gram	14
Berseem	4
Wheat	0.5

Chak 25/11-L.—(belonging to R. S. Ch. Bahadur Chand).

In this chak the water-table is deep, about 40 feet from the natural surface. During 1939 R. S. Ch. Bahadur Chand informed the Chief Engineer that his lands were deteriorating on account of *thur* and that a considerable portion of the area had gone out of cultivation. The matter was investigated and it was found that the statements made by the Rai Sahib were supported by the records of the civil patwari. One cusec of extra water was sanctioned for reclamation in this area during kharif, 1940. Approximately 42 acres of rice were sown which gave an average yield of 16 maunds per acre. After rice the following crops have been sown:—

	Acres.
Gram	16
Berseem	16

The condition of the rabi crops is satisfactory.

Chak 126/15-L.—(belonging to S. B. Ujjal Singh, M.L.A.).

The whole of this chak is of the bara type. The Sardar Bahadur had been attempting reclamation of the area by the addition of silt. This had not been successful as indicated by crop yields. Cotton in the area is almost always attacked by *tirak*. The whole of the water-supply allotted for the village has been utilised in the portion that has been improved by the addition of silt. The Sardar Bahadur obtained two cusecs of water for reclamation on a contract basis with effect from kharif, 1940. Fields which had received no dressing of silt were selected for reclamation. A soil survey was made which showed that the area was alkaline and had reached the *Rakkar* stage. The Sardar Bahadur was informed that reclamation could not be completed with less than three rice crops. The Sardar Bahadur agreed. During kharif, 1940, 101.5 acres of rice were sown. Although rice had not been a complete success, the Sardar Bahadur's tenants requested him to give that area to them on lease during the rabi season. Instead of giving land to the tenants the landlord has sown under direct cultivation, gram in 27 acres and berseem in 23 acres. From a report by the Sardar Bahadur, berseem is likely to sell at Rs. 50 per acre. It is proposed to during kharif, 1941. In addition a sanctioned as the area proposed ximately.

B. C. G. A. (Khanewal).—Complaints had been made that in spite of good cultivation at this farm the yields of crops particularly

of cotton had declined from an average of 16 maunds of cotton to between 3 to 4 maunds. Patches of *thur* had started appearing in cotton fields and it was stated that *thur* was on the increase. At the request of Sir William Roberts a visit was paid to the estate and a soil survey was carried out. It was found that salts were present in the soil crust in the majority of the profiles and that the salt in the soil crust was responsible for the appearance of *thur* at the surface. At the request of B. C. G. A. five cusecs of extra water was sanctioned by the Chief Engineer to start experiments :—

- (a) to prevent the upward movement of the zone of accumulation of salt ;
- (b) to depress this zone to a depth of more than 6 feet so that yields of cotton and other crops may improve ;
- (c) reclamation of *thur* land where the zone of accumulation had reached the surface.

During kharif, 1940, 183 acres of rice were sown which gave an average yield of 13 maunds per acre. After rice gram has been sown in 68 acres on wadh-wattar ; berseem in 49 acres under rabi irrigation and wheat in 15 acres after an application of farmyard manure. The germination of the rabi crops is good. A soil survey is in progress to determine the salt content and the alkalinity in the soil profile to enable fields to be selected for cotton and sugarcane for kharif, 1941. During kharif, 1941, reclamation will be restricted to an extra supply of three cusecs only.

Costing accounts are being maintained for all areas on contract supplies of water. As the system of cultivation and the terms with the tenants differ with different landlords in different localities, the costs vary in each case. This is the first year of reclamation on contract supplies in the Lower Bari Doab Canal. Costs have not been given in this report as, from the soil surveys, it seems that the areas are only partially reclaimed and that rice should be sown again in kharif, 1941. This aspect will be dealt with in the report for the year 1942.

Lower Chenab Canal.

On the Lower Chenab Canal extra water for reclamation had been obtained by Pir Diwan Ali ; Raja Narindra Nath ; Raja Sir Daya Kishan Kaul and Gurdwara Nankana Sahib. The chaks belonging to these landlords are situated in the region where rapid deterioration is taking place.

Kot Diwan Ali.—This chak belongs to Pir Diwan Ali Shab and almost the entire chak has become *thur* so much so that the majority of the tenants had left the place and the village was more or less deserted. An extra supply of 1.5 cusecs was sanctioned and reclamation was started in kharif, 1940. A trained Village Assistant was posted to supervise the reclamation operations. A total area of 198.5 acres was sown under rice. This gave an average yield of 14 maunds

per acre. The area under rice is more than could be matured on the extra water-supply sanctioned. The increase in the area under rice is due to the fact that the old allotted water-supply of the zemindar was also utilised for reclamation. This is an instance of an area where deterioration had reached a stage that even the normal water-supply could not be utilised for cultivation. During rabi the following crops have been sown :—

			Acres.
Gram	..	..	16
Wheat	..	..	17
			After an application of farm-yard manure.
Berseem	..	..	15

The condition of the standing crop is good and normal yields are expected.

In this village reclamation is being done by tenants themselves. They bear all the costs and get three-fourth of the whole produce, one-fourth being the share of the landlord.

Chaura Sagar.—(belonging to Raja Narindra Nath).

Reclamation has been taken up in this village with an extra water supply of two cusecs. Approximately 99 acres were put under rice which gave an average yield of 19 maunds per acre. During the rabi gram has been sown in 34 acres and wheat in 2 acres. As the jhona crop was harvested late it was not possible to sow any berseem. From the examination of the soils of the area after rice it has been decided that the land is only partially reclaimed and that a further crop of rice should be taken. Costing accounts are being maintained and will be presented in the report for the year 1942.

Chak 236-G. B.—(belonging to Raja Sir Daya Kishen Kaul).

In addition to the *thur* girdawari Raja Sir Daya Kishen Kaul himself has kept a record of fields affected by *thur*. According to his records out of a total area of 500 acres, 112 acres were affected by *thur* in rabi, 1938-39; 151 acres in rabi, 1939-40 and according to the latest survey in 1940-41 the *thur* area was 185 acres. During 1940 Raja Sir Daya Kishen Kaul applied for an extra supply of water for reclamation. As his application was received sometimes in June and the season was getting late for rice, he was advised to undertake reclamation during the year 1941. Raja Sahib was so afraid of the rapid deterioration that he insisted on his application being considered for kharif, 1940, even though he was late to get full advantage of the extra water supply sanctioned. The soil survey of the area showed that reclamation could be carried out with two rice crops. Two cusecs of extra water were sanctioned for his area and that belonging to Pandit Brij Lal Takru in the same village. This extra water was not available till about the end of July. With insufficient leaching, therefore, rice was sown in an area of 44 acres which gave an average yield

of 18 maunds per acre. During the rabi following rice, gram, berseem and wheat have been sown. The condition of crops is above normal.

Gurdwara Nankana Sahib.—The estate belonging to the gurdwara comprises an area of 17,000 acres approximately. Out of this 2,850 acres have become *thur*. The annual deterioration is of the order of about 600 acres. The Gurdwara Committee applied for extra water for reclamation so that they are able to reclaim at the rate of the annual deterioration. As the application was received late they were advised to start a small experiment in the first year and extend it during the subsequent years. During kharif, 1940, two cusecs of extra water supply was sanctioned late in the season. Rice was sown in an area of 76 acres which gave an average yield of 14 maunds per acre. Considerable improvement has taken place but from the soil analyses it is concluded that another rice crop should be sown. During rabi following crops have been sown :—

	Acres.
Gram	64.5
Berseem and senji	11

The condition of the rabi crops is good. The growth of gram is excellent.

Upper Chenab Canal.

On the Upper Chenab Canal a very small area of deteriorated land has been brought under reclamation by S. Sampuran Singh, M.L.A., in village 10/63 on an extra supply of half a cusec of water. The extra water-supply was not given till about the 8th of August. With very little preparation an area of 16.5 acres was put under rice. This gave an average yield of 23 maunds per acre. During rabi, berseem has been sown in 15 acres.

Lower Jhelum Canal.

On the Lower Jhelum Canal extra water supply has been sanctioned for reclamation of *thur* land in villages Sher Mohd. Wala, Fatehpur, Mari and Chak 190-N. B. During kharif, 1940, rice was sown in 70 acres of *thur* land at Sher Mohd. Wala and following rice, gram has been sown barani which is likely to give normal yield.

In village Mari, rice was sown in 18 acres on 0.5 cusec of extra water out of which gram has been sown in 11 acres after rice. The germination of gram is good.

In village Fatehpur, this is the first year of reclamation. Forty four acres of *thur* were put under rice. The condition of land after rice indicates that another rice crop should be taken before normal cropping can be introduced.

In Chak 190-N. B. *thur* land has carried two rice crops. From the condition of the standing rice crops and from an examination of soils made previous rabi, it was known that some fields were suitable for normal rotation. A cropping scheme was framed but was not taken up by the landlord.

Upper Bari Doab Canal.

Village Amirpura.—(belonging to Raja Narindra Nath).

A considerable portion of this village has deteriorated and is lying in that condition for a long time. An examination of soil profiles showed that the land belongs to the Rakkar type. The Raja Sahib was informed that reclamation of this land will not be possible in less than three rice seasons. To this the Raja Sahib agreed and stated that he would be satisfied if he is able to get an average yield of 10 maunds of rice from the deteriorated area. An extra water supply of 2.5 cusecs was sanctioned and 117 acres of rice were sown. The early crop of rice gave an average yield of 18.5 maunds per acre. The late crop was attacked by the borer. As the harvesting of the *jhona* crop was late it was not possible to sow any rabi crops. Rice will be sown again during kharif, 1941.

Amritsar district.—In the year 1938, Mr. MacFarquhar, the Settlement Officer, Amritsar, stressed the necessity for an examination of the soils of the district and sought the advice of the Institute regarding the reclamation of large tracts of banjar land which had developed *thur* but which had been entered in the civil records as culturable. Proposals and estimates for a soil survey of the district were prepared by Mr. MacFarquhar who forwarded them to Government. These were not sanctioned. In the meantime Mr. MacFarquhar approached the Financial Commissioner for a start to be made in land reclamation in the district. *Village Ramdass* in which a compact block of banjar *thur* was present was selected for experiment. A visit was paid to this village. From an examination of the soils it was found that the deterioration had reached the Rakkar stage. The only water supply available for reclamation was either rain or an uncertain supply from the Kirn Canal. Kirn Canal is under the control of the District Board, Gurdaspur. Rice cultivation is carried out on this canal but wells are worked at times when the monsoon is poor and the supply in the canal runs short. During the rabi wells are abandoned and after rice land is left fallow.

Before undertaking reclamation on a large area it was decided that a small experiment should be carried out during kharif, 1940, to study the conditions of the water-supply, the rainfall and the quantities of well water required to mature rice and also the effect of sowing leguminous rabi crops following rice on the salt content and the alkalinity of the soil.

9.5 acres of rice were sown during kharif, 1940. Wells had to be worked for an area of 4.5 acres to mature rice. Rice in

the remaining 5 acres was matured on rain plus any water that was available from the Kirn Canal. The area where well water was also used gave an average yield of 28.4 maunds of rice. The yield of rice from the remaining area was 16.1 maunds per acre. During Rabi, the following crops have been sown :—

Berseem .. 2.5 acres on well irrigation.

Senji .. 1.5 acres on well irrigation.

Gram .. 1.5 acres barani.

An examination of soil profiles from fields after rice has been made. The results of analyses indicate that considerable improvement has taken place. The salt content and the alkalinity have been reduced in the first two feet. It is proposed to sow rice again in kharif, 1941.

The Chakanwadi Reclamation Farm.—The Chakanwadi Reclamation Farm which comprises an area of 3,600 acres was utilised for the development of methods of reclamation of various types of land. In 1936 under orders of Punjab Government the experimental work at this farm was stopped and the land was handed over to a lessee. The lessee neglected the drainage system with the result that in a portion of the farm the fields were wholly occupied by grass and weeds. In the year 1939, the area was resumed by Government for experimental work in connection with problems arising out of land reclamation and development of new project areas.

During rabi, 1939-40 and kharif, 1940, 600 acres out of the area that was neglected by the lessee was brought under cultivation again. The total expenditure on the farm was Rs. 19,000 and the total expected income Rs. 33,000.

1. *General.*—It has been stated in the introduction to this report that the most general characteristic of Punjab soils is the presence of a salt-bearing layer in the soil crust. Under irrigation the salt accumulates in the soil solution and travels up or down according to the quantity of water applied and the crops grown. The beginning of the first stage of deterioration is noticed, when the salt enters the root zone of crop with the deepest root system. During the past several years reclamation has been in progress on a number of estates in the Lyallpur and Montgomery Colonies. In these colonies complaints of the attack of tirak on American cotton have been made for some time. In certain parts, however, the damage due to tirak has been considerable. It has been observed that tirak does not occur on cotton grown on reclaimed land adjacent to tirak affected cotton. This observation applies to all the reclaimed areas. The probable explanation is that tirak is caused by the presence of salts or alkalinity in the soil which develops as a result of salt action on clay. The appearance of tirak therefore, indicates the first stage of land deterioration. If land is put under rice at this stage it will not only remove the salt from the root zone of cotton and consequently increase its yield but will also prevent its upward movement and save the land from complete deterioration.

irrigation will be possible. In the salt area it will be necessary to determine the length of the period of leaching required to remove the salts permanently from the root zones of the various crops and the number of rice crops that will be required to remove the residual alkalinity. In the alkaline area the main problem will be the number of rice crops which will be required to reduce the alkalinity to a satisfactory value for the introduction of normal cropping. Upon the solution of these two problems will depend the time required for the complete development of the area.

In the alkaline areas there is likely to be little seepage from the water-courses and little difficulty in the introduction of the perennial system of irrigation once the deteriorated conditions are eliminated. Dust storms in the Leiah area are likely to be a factor requiring consideration in connection with the sowing dates.

3. *Patti areas.*—In this type of land, the zone of accumulation of salts and high alkalinity occurs at some depth below the surface. From the experience of the older irrigation projects it is anticipated that under normal perennial irrigation the zone of accumulation of salts will travel towards the surface and cause the land to become *thur*. The main problem to be investigated in this area will be to compare the effect of perennial irrigation as understood in the canal colonies and rice cultivation on the land in which deterioration is expected to occur. Unless a correct method of development is worked out, the soil conditions indicate that soil deterioration will be experienced in the future when water may not be available in sufficient quantities to arrest it.

In order to obtain information on the problems enumerated above, small plots of land typical of each type have been acquired for experimental development on tube-well water. It is proposed to add silt to the tube-well water in the same proportion as is found in the Indus water. The tube-wells have been sunk. It has been found that the sub-soil water at the Kundian, Bhakkar and Patti areas on the Bhakkar-Trimmu road are suitable for irrigation. Difficulties are being experienced in obtaining satisfactory supplies of sub-soil water at the Leiah and Khushab sites. At the Leiah site the water at a depth of 188 feet is just suitable for irrigation. Lower down the water is again unsuitable. It is proposed to install the strainer at a depth between 120 feet and 200 feet at the Leiah site. For the Khushab site it is proposed to install the tube-well nearer the river and to bring water for irrigation to the land acquired for experiment in a lined channel.

It is expected that it will be possible to start the experimental work during kharif, 1941.

Seepage losses from the bed of the proposed Khushab Branch.—The Chief Engineer wanted to determine the probable absorption losses from the bed of the proposed Khushab Branch and the reaches in which lining would be necessary. Soil profiles were dug from R. D. 500

to R. D. 150,000 of the proposed alignment of the Khushab Branch at distances of 5,000 feet and samples taken for examination. These samples were examined for their texture and for pH values and salt content. From the analyses it was found that the soil from R. D. 500 to R. D. 70,000 is of such a character that seepage from the bed and the sides will be high. From R. D. 70,000 to R. D. 150,000 the clay content is high so that the bed of the channel will be less permeable. In some portions of this reach, however, the salt content of the soil is high. On account of the high salt content, seepage will be high at the beginning but on account of the production of sodium clay impermeability will develop and the seepage losses will be gradually reduced.

Canals in the Thal and wind-blown sands.—At Kalabagh and in the canal, a silt excluder and ejectors are to be constructed. These will deal with silt entering the head of the canal. In the kharif season dust-storms are of daily occurrence and may contribute to the silt load carried by the water. As it is proposed to line the canal, the maximum size of the sand likely to be thrown into it is of considerable importance since that will affect the rugosity, one of the factors upon which the discharge will depend. To obtain information on this point samples of sand transported by the dust-storms were collected at various sites. For this purpose wind-breaks were constructed at R. D. 25,000 and R. D. 200,000 of Main Line Lower and in the Leiah area. These samples were examined for particle size and their distribution curves were drawn. Typical curves are given in Fig. 199, 200 and 201. It appears from these curves that sand up to a diameter of .6 mm., may be blown into the canal. It must be expected that the material in the bed will have a diameter of .6 mm.

Kasses carrying salt-charged water from the Salt Range to the plain area proposed for irrigation in the Thal.—During the course of the soil survey it became known that some of the kasses from the Salt Range carry salt-charged water during the monsoon and spread themselves on the red alkaline area in the north-west of the project. The routes of the following kasses were traced:—

(i) *Kauri Wan.*—It takes off at a distance of 1½ mile from the west of Warchha salt mines and ends near Gujyal railway station.

(ii) *Dhodha Wan.*—This kassi starts from Ardi north of S. S. south of Skesar. At its source the water is fully salt charged with salt. The torrent ends near Bandial.

(iii) *Kauri Wan.*—It starts from the Salt Range near D. D. 125,000 and ends at a distance of about 4 miles from the proposed irrigation boundary.

(iv) *Jaswal Wan.*—This kassi carries salt charged water. It crosses Corbyn inundation and ends near the R. D. 125,000. It floods the Rakh Rajar area.

TABLE 52.
STATEMENT SHOWING COSTS OF RECLAMATION IN THE SUKHEKI AREA.

Name of Chaks.	Ares taken up for reclamation in acres.	Kharif, 1939.			Rabi, 1939-40.			TOTAL Kharif, 1939 AND Rabi, 1939-40.			REMARKS.
		Area under rice in acres.	Net value of produce after deducting expenses.	Profit per acre.	Area under crops in acres.	Net value of produce after deducting expenses.	Profit per acre.	Area under crops in acres.	Total net value of produce after deducting expenses.	Pr fit per acre.	
			Rs. A. P.			Rs. A. P.			Rs. A. P.		
112.R.B.	53.29	50.40	735 9 0	14.59	38.1	1,506 8 9	41.38	50.40	2,312 1 9	45.88	
113.R.B., Plot A.	53.28	50.10	959 11 9	19.16	33.96	1,580 14 9	46.55	50.10	2,540 10 6	50.71	
113.R.B., Plot B.	71.79	44.78	621 7 6	13.88	33.2	1,372 11 9	41.35	44.78	1,994 3 3	44.53	
114.R.B.	146.06	125.13	1,997 0 9	15.96	74.41	3,416 9 3	45.92	125.13	5,413 10 0	43.26	
115.R.B.	174.35	129.17	2,037 3 3	15.77	98.23	4,750 5 0	48.36	129.17	6,787 8 3	52.55	

Water rate and land revenue on the basis of new schedule	Total Profit	Rs.	A.	P.
		19,018	1	9
		4,694	7	0
	Net Profit	14,353	10	9
	Profit per acre	35.8		

TABLE 53.

Renala Estate, District Montgomery.

RECLAMATION ACCOUNT.

Year.	—	Debit.	Credit.
1938.		Rs. A. P.	Rs. A. P.
27th June	.. To cash paid to Sub-Divisional Officer, Canal Renala Khurd, for building a culvert on the Renala-Natchara Road for extra supply of water.	131 0 0	--
Ditto	.. To telegram to Land Reclamation Officer, Lahore, for rice seed.	3 6 0	--
28th June	.. To travelling allowance to B. Bishan Dass, Godown keeper for Okara trip.	1 6 0	--
Ditto	.. To additional money sent to Sub-Divisional Officer, Renala Khurd, for construction of new culvert.	185 0 0	--
4th July	.. To cost of 29 carts manure from Dairy at Re. 0 8 0 per cart.	14 8 0	--
Ditto	.. By amount excess paid to Sub-Divisional Officer for making culvert on 28th June, received back.	--	66 0 0
Ditto	.. To additional money sent to Sub-Divisional Officer for the construction of new culvert.	123 0 0	--
Ditto	.. To stationery supply during June, 1938.	1 10 0	--
Ditto	.. To store supply during June, 1938 ..	22 4 6	--
7th July	.. To railway freight on 8 bags Moony from Kala Shah Kaku.	1 11 0	--
Ditto	.. To railway freight on 2 bags Moony from Kala Shah Kaku.	0 12 0	--
11th July	.. To labour and stores on works in June, 1938.	3 15 0	--
15th July	.. To cost of 6 empty baskets at Rs. 0 1 3 each	6 10 6	--
18th July	.. To wages to Bellars for June and July.	65 14 0	--
22nd July	.. To money order to Assistant Commr. Kala Shah Kaku, for cost of rice seed and money order commission	53 8 0	--
2nd August	.. To Colonel Bruce, Travelling Allowance for Lahore trip 2 days	20 0 0	--

TABLE 53—CONTD.

Year.		Debit.	Credit.
		Rs. A. P.	Rs. A. P.
1938— <i>concl'd.</i>			
28th November	To telegram to Land Reclamation Officer, Lahore.	1 3 0	..
30th November	To 4 seers gur for mixing with berseem seed.	0 8 0	..
Ditto	To exchange on cheque from Land Reclamation Officer, for Rs 48-14 0.	0 4 0	..
Ditto	To grains from godown for bullocks in October, 1938.	3 12 0	..
9th December	To wages to Beldars for November ..	57 13 0	..
19th December	To stationery supply in November ..	0 2 6	..
26th December	To hire of Estate Car, 6 miles in November.	0 12 0	..
Ditto	To grain ration, Mds 4-12-0 in November.	10 3 0	..
27th December	To labour on works in November ..	1 5 0	..
1939.			
12th January	To stationery in December ..	0 4 3	..
17th January	To wages to Beldars for December ..	14 14 0	..
21st January	To labour and material on works in December.	2 9 0	..
25th January	To hire of Estate Car, 19 miles in December.	1 7 0	..
31st January	By refund from Sub-Divisional Officer, Renala Khurd. Balance from amount deposited last year for construction of culverts.	.	248 0 0
Ditto	To exchange on cheque from Sub-Divisional Officer.	0 15 0	..
4th February	To stationery in January ..	0 9 0	..
Ditto	To stores " " ..	4 13 3	..
15th February	By cash sale of green fodder ..	..	25 2 0
Ditto	To wages to Beldars for January ..	15 15 6	..
24th February	To labour and material on works in January.	6 12 6	..
6th March	To wages to Beldars for February ..	11 4 0	..

TABLE 53—CONTD.

Year.		Debit.	Credit.
1939—contd.		Rs. A. P.	Rs. A. P.
13th March	To stationery in February	0 9 0	—
14th March	To wages to Khushi Muhammad, Beldar, 5th January.	2 3 0	—
20th March	To wheat seed for sowing, Mds. 1.20-0 at Rs. 2.	3 0 0	—
22nd March	By cash sale of green berseem	—	56 4 0
31st March	To stationery in March	0 7 0	—
Ditto	To stores supply in March	3 12 3	—
Ditto	By cash sale of green fodder	—	12) 3 3
Ditto	By green wheat 10 kanal to dairy bullocks, at Rs. 3.	—	30 0 0
Ditto	By tenants, etc., green fodder	—	41 3 0
Ditto	To cost of 12 maunds, Moony seed in March at Rs. 2 and empty bags.	25 8 0	—
Ditto	By cost of 4 seers gur twice vouched adjusted on checking.	—	0 8 10
Ditto	To wages to labour for March	15 6 0	—
11th April	To cartage of bricks for works	7 0 6	—
21st April	To wages to Allah Din, Beldar, 6th April.	2 8 0	—
24th April	By cost of green berseem sold	—	12 0 0
4th May	To wages for making a culvert	5 4 0	—
6th May	To stationery supply in April	0 1 2	—
Ditto	To stores, 4 maunds ammonia sulphate in April	17 12 0	—
16th May	To wages to Beldars for April	27 0 0	—
6th May	To telephone call to Mr. Bigsby, Lahore, on 1st April.	1 8 0	—
23rd May	To exchange on Sub-Divisional Officer Cheque.	0 4 0	—
Ditto	To labour and stores on works in April	75 16 6	—
6th June	To wages to Beldars for May	60 14 3	—

TABLE 53—CONTD.

Year,		Debit.	Credit.
		Rs. A. P.	Rs. A. P.
1939— <i>concl'd.</i>			
8th November	To cost of 3 telephone trunk calls to Lahore.	6 0 0	—
Ditto	To wages to Beldars for October ..	32 12 3	..
14th November	To stationery supplied in October .	1 15 3	..
Ditto	To stores, berseem seed and kerosene oil, etc., in October	73 7 3	..
20th November	To wood supplied for Sohagas ..	13 2 0	..
Ditto	To labour on works in October .	0 3 0	—
26th November	To hire of tonga 1 trip in October	0 6 0	..
11th December	To stationery supplied in November	1 15 6	..
Ditto	To stores, berseem and senji seed, sugar, etc., in November.	194 8 0	..
14th December	To wages to Beldars engaged in November.	34 2 0	—
22nd December	To salary paid off to Munshi Dewan Chand, December days	9 3 0	..
31st December	To hire of tonga 1 trip in November	0 6 0	..
1940.			
6th January	To stationery in December ..	1 2 0	..
12th January	To wages to Beldars for December ..	10 14 0	..
15th January	To stores supplied in December ..	0 11 6	..
26th January	To labour and stores in December on works.	5 13 6	..
9th February	To wages to Beldars for January	7 14 0	..
13th February	To stationery supplied in January	0 7 6	—
19th February	To stores in January	31 1 6	..
21st February	To labour and stores on works in January.	29 11 0	..
29th February	To Sepi to carpenter for <i>khari</i> , 1939	15 0 0	..
7th March	To wages to labour engaged in February.	10 14 0	..
15th March	To cost of gur 20½ seers to cartman. ..	2 9 6	..
Ditto	To stores supply in February ..	3 12 0	..

TABLE 53—CONTD.

Year.		Debit.	Credit.
1940—contd.		Rs. A. P.	Rs. A. P.
1st March	.. To labour on works in February ..	0 12 0	..
31st March	.. To gur 26½ seers to little cartmen ..	3 5 0	..
Ditto	.. To wood used on works in March ..	12 11 0	..
Ditto	.. To wages to labour during March .	12 6 0	..
Ditto	.. To stationery and stores in March ..	2 9 9	.
Ditto	.. To gram seed, Mds 28 14-0 at Rs 2-12 0 in October for Renala Khurd.	77 4 6	
Ditto	.. To gram seed, Mds 4-26 0 at Rs 2 12-0 in October for Renala Kalan	12 12 9	
Ditto	.. To labour and stores on works in March	8 3 0	
Ditto	.. To moonji seed and wheat seed supplied during ½ year.	51 8 0	
Ditto	.. By produce received during ½ year— American Kappas, Mds 23 23 4 at Rs. 9 6 9 per maund Moonji Kappas, Mds 166 37 7 at Rs 2 per maund		222 6 0 334 6 0
18th April	.. To wheat, Mds 2 25 0 in lieu of cutting senji.	8 6 0	
24th April	.. By sale of senji and berseem		150 10 0
6th May	.. By Dairy cost of 14 kanal berseem		37 4 0
Ditto	.. By tenants, senji and berseem, etc., Rabi, 1939-40.		147 4 0
13th May	.. To labour engaged during April ..	72 6 0	
17th May	.. By horses cost of 11 kanal berseem at Rs 2 per kanal.		22 0 0
8th June	.. By cash sale berseem, Rabi, 1939 40		42 1 0
24th June	.. By tenants and dairy cost of berseem, Rabi 1939 40		23 12 0
Ditto	.. By other produce received for Rabi 1939 40— Wheat, Mds 410 29 15, valued at Rs 2 8-0, average rate. Gram, Mds 421-7-11, valued at Rs 2-12 0, average rate. Berseem seed, Mds 15 8 0 at Rs 10 per maund. Senji seed, Mds, 57 0-0 at Rs. 2 per maund. Bhoosa, Mds, 613-20-0 at Rs. 1-6-0 per maund.		1 026 14 6- 815 14 152 0 114 0 192 0 0



FIG. 185.

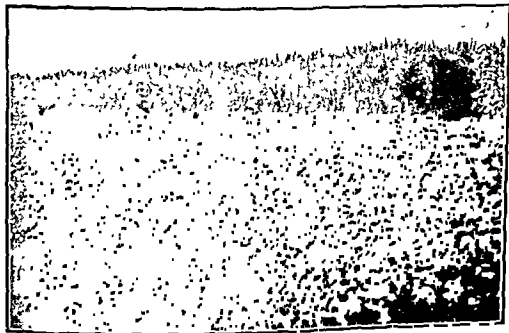


FIG 187

PART PLAN OF PUNJAB
SHOWING SITES WHERE RECLAMATION IS IN PROGRESS
IN YEAR 1940.....●

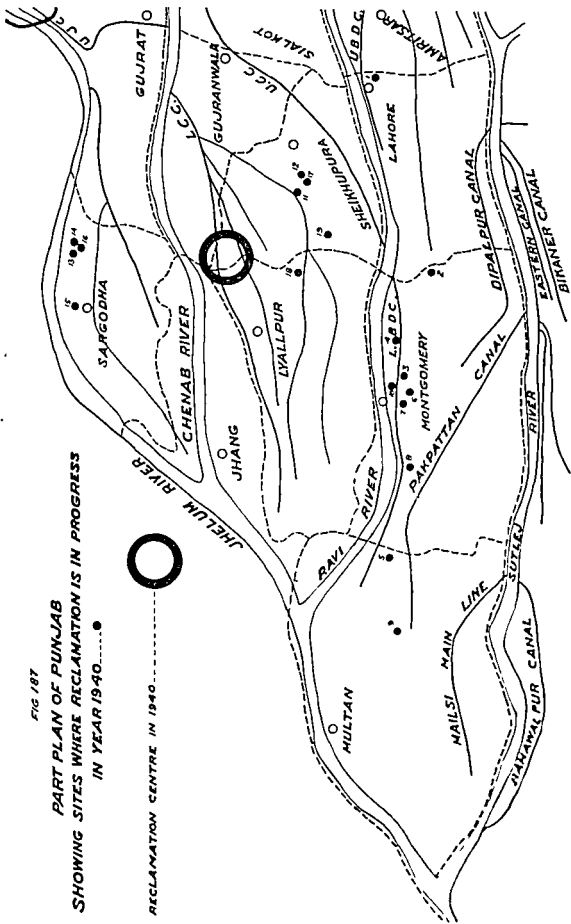


FIG. 188.



FIG 189

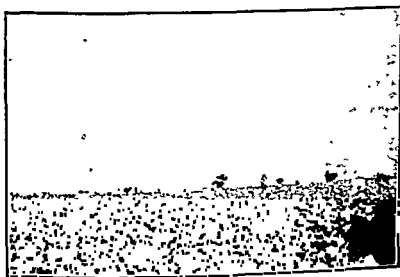


FIG 190.

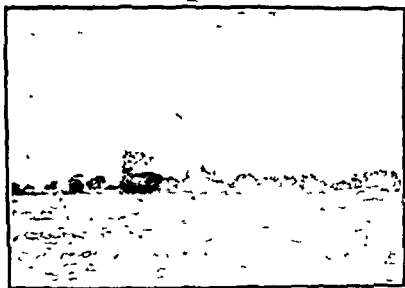
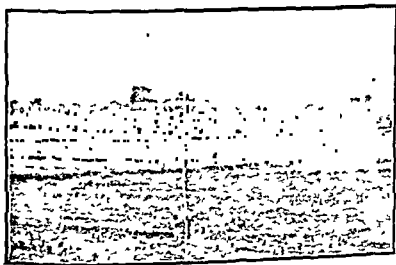


FIG 191



Sugar cane in undeteriorated area

Sugar cane in reclaimed land

FIG. 192.

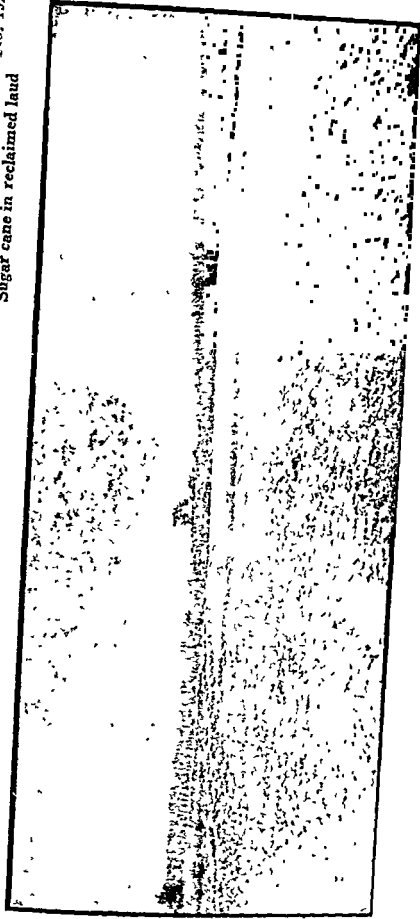




FIG 194

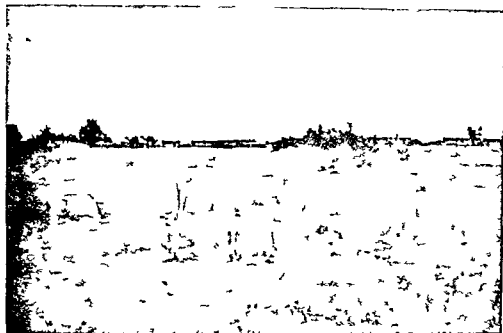
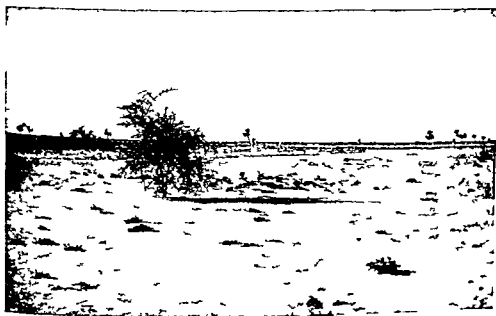
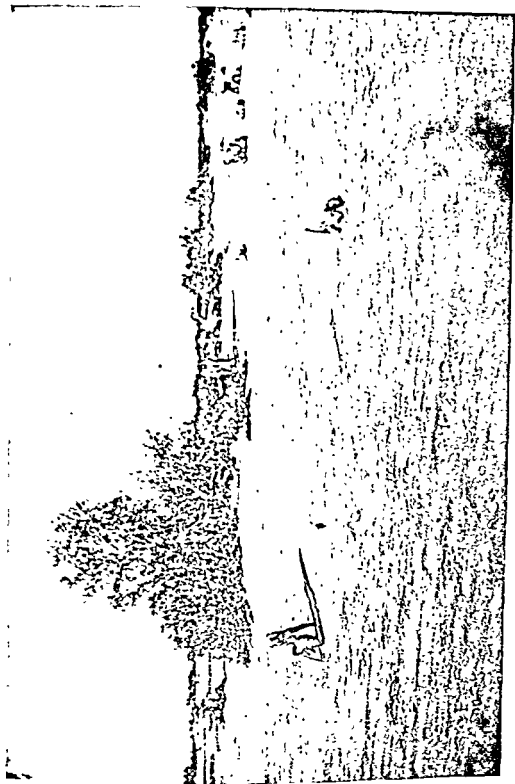
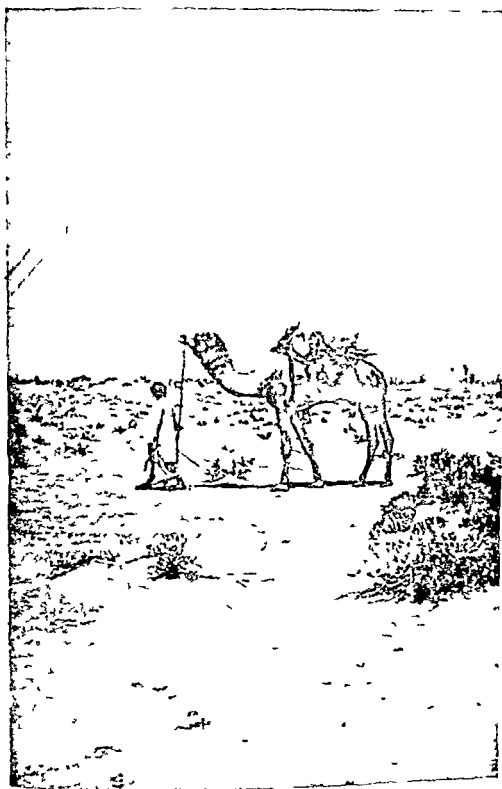


FIG 195







**SURFACE SOIL MAP
OF
THAL PROJECT AREA**

FIG. 138

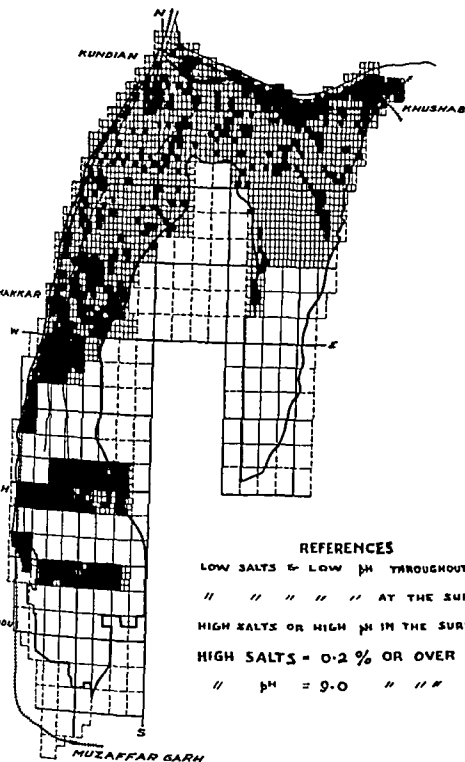


FIG. 199

SIZE DISTRIBUTION CURVE

OF WIND-BLOWN SAND

RD 25,000 MAIN LINE LOWER

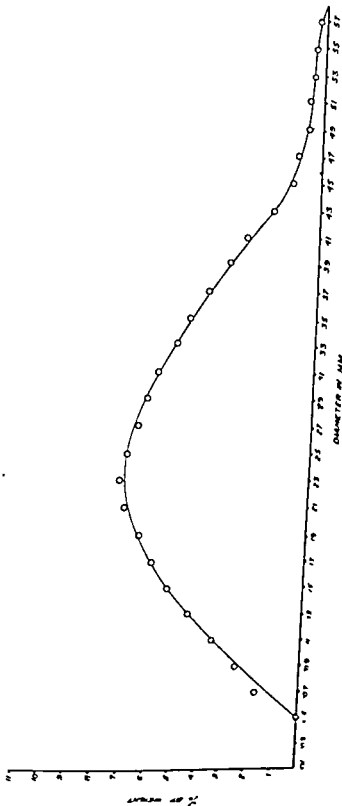


FIG 2.00

SIZE DISTRIBUTION CURVE OF WIND-BLOWN SAND

CROSSING OF MUNDA BRANCH AND LEJAN-NANAKOT ROAD

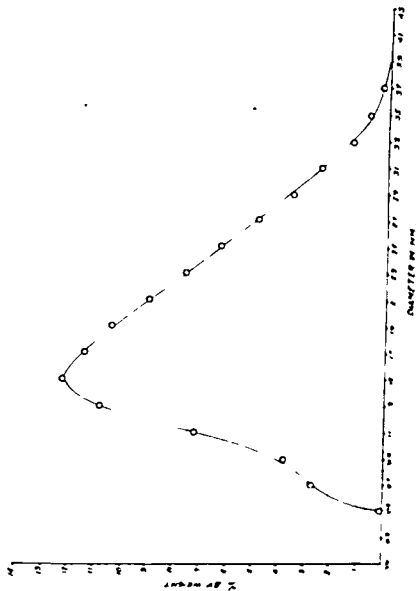


FIG. 201

SIZE DISTRIBUTION CURVE

OF WIND-BLOWN SAND

RD 200 000 MAIN LINE LOWER

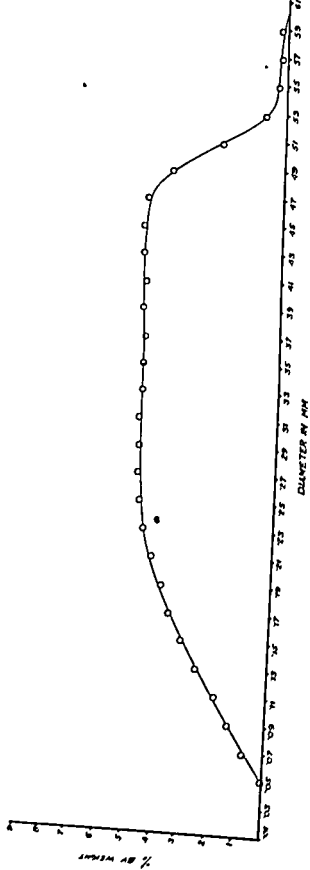


FIG. 202
 EROSION OF TIBBAS BY DUST-STORMS
 PLAN SHOWING THE LEVELS OF SAND IN THE TIBBA

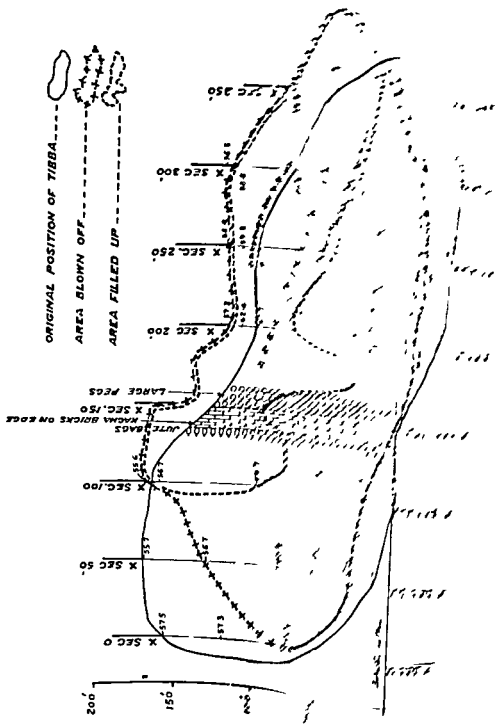


FIG. 203
MAP SHOWING PERCENT THUR AREA
IN SELECTED VILLAGES OF LYALLPUR DISTRICT

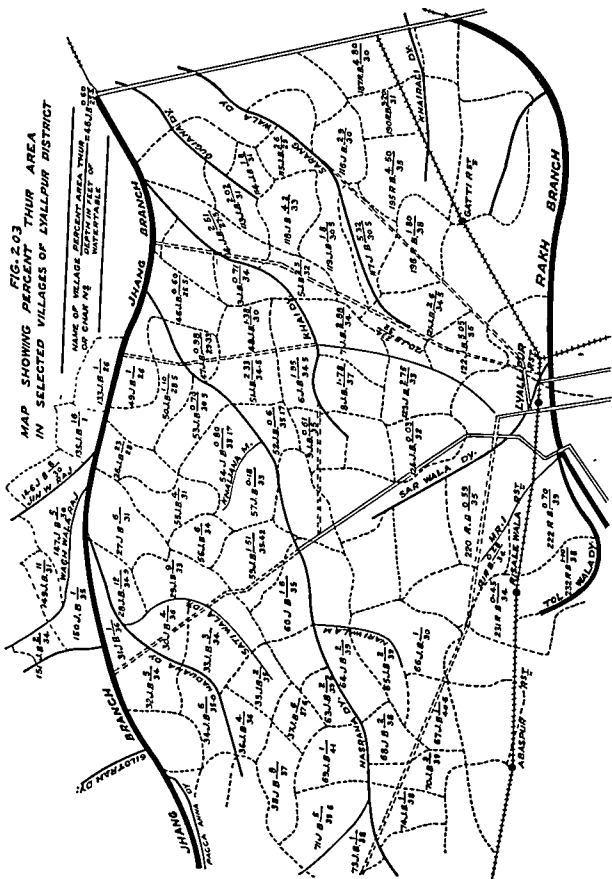
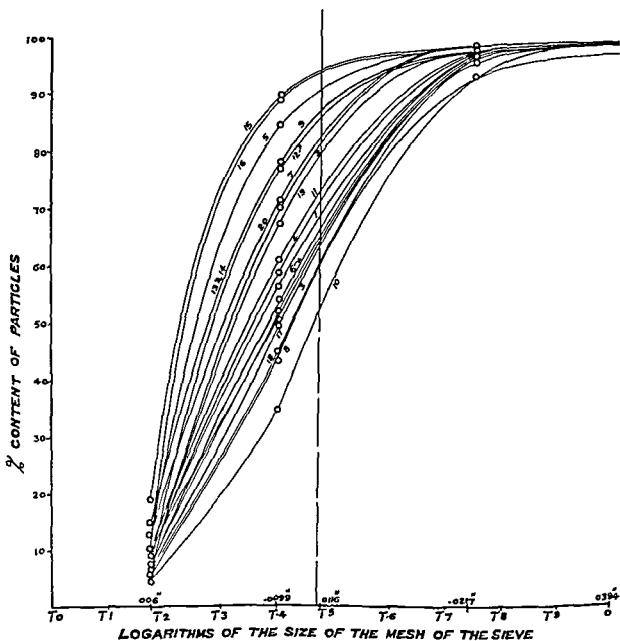




FIG. 204
SUMMATION CURVES
OF THE VARIOUS SAND SAMPLES ON SEMI LOGARITHMIC SCALE



GENERAL SECTION.

THE work of the section, during the year, may be dealt under two heads, viz., analytical work of a routine nature and research work :—

(a) Analytical and Advisory Work.

(i) *Examination of samples of sand to be used for making cement-mortar for brick lining of canals.*—The employment of fine grained sand for making cement-mortar has been shown to be a source of weakness. A number of sand samples from the Haveli Main Line were received for analysis and report as to their suitability for use in preparing cement-mortar.

The sands were analysed by sieving. The results for a few sand samples have been presented in the form of summation curves plotted on semi-logarithmic scale in Figure 204. Mr. Haigh in his note dealing with the Report of the Committee which investigated the Haveli lining laid down the specification for defining the suitability of sand for this purpose. According to his specification, samples of sand having more than 3 per cent particles finer than 0.006" and 25 per cent finer than 0.0116" might be considered unsuitable for use in making cement-mortar. The 0.0116" limit is represented in the figure by the thick vertical line running near the centre of the figure. It will be seen that the majority of the curves indicate a greater percentage of particles finer than 0.0116".

(ii) *Examination of strata soil samples from Jaba Weir.*—Over 400 soil samples, taken from the 16 bays of the Jaba Weir, were received for examination. The soil samples were analysed for total salt content, pH, clay content on auto-disintegration (D.F.) and total clay content. From the results of (D.F.) and total clay the dispersion co-efficient was also derived. A report, based on the results of analysis of these soil samples, was submitted.

(iii) *Examination of soil samples from the proposed kiln sites.*—A very large number of soil samples was received from Daud Khel, Bhakkar, Mianwali, Trimmu, Drain Section Quam, Tosham Sub-Division (Western Jumna Canal), etc., from the proposed kiln sites to report on their suitability for brick making. These samples were examined for their soluble salt, clay and calcium carbonate contents and on the basis of the analytical results the suitability, or otherwise, of the soils received from various places was reported.

(iv) *Work for the Land Reclamation Department.*—A large number of sub-soil water samples from Rajoa and Renala areas were analysed for the Land Reclamation work.

(v) The water and strata soil samples continued to be received from the Karol Tube-well Project. These were analysed and results reported.

(b) Research work.

1. *The conductometric method of determining the soluble salt content of soils for use in soil survey work.*—The classification of soils for project and land reclamation work in the Punjab is based on the soluble salt content of soils and their pH values. In recent years fairly robust pH meters for field work have been evolved. The determination of the soluble salt content of soils is, however, done gravimetrically. The method is laborious and necessitates the carriage of an elaborate equipment in the field. There are instruments, e.g., the Dionic water tester, etc., which afford a measure of the salt content of solutions in terms of electrical conductivity. The possibility of using such an instrument for measuring the conductivity of soil suspensions and the interpretation of the conductivity in terms of the percentage salt content of soil was examined.

A difficulty in using such a conductometric method of determining the salt content of soil is that the relation between the electrical conductivity of solutions and their salt contents is known to be linear only in very dilute solutions. Extremely thin suspensions of soil might, therefore, have to be used.

The effect of dilution of soil suspensions on conductivity was studied for a number of soils at dilutions ranging from 1 : 5 to 1 : 150 soil-water ratios. On plotting, a parabolic relationship, analogous to that obtained with true salt solutions, was evident. The results showed that it would be feasible to adopt one particular dilution of the soil suspension and by examining a number of soils of varying salt contents to derive the most suitable conductivity : soluble salt relationship for that soil-water ratio.

A number of soils were examined for their conductivities at 1 : 5, 1 : 30 and 1 : 50 soil-water ratios. The following statistical relationship between the conductivities (C) and the directly determined total salt content of soils (S) were obtained:—

For 1 : 5 soil suspensions

$$10^3 S = 0.314 C + 25.4 \quad (i)$$

For 1 : 30 soil suspensions

$$10^2 S = 0.17 C - 2.8 \quad (ii)$$

For 1 : 50 soil suspensions

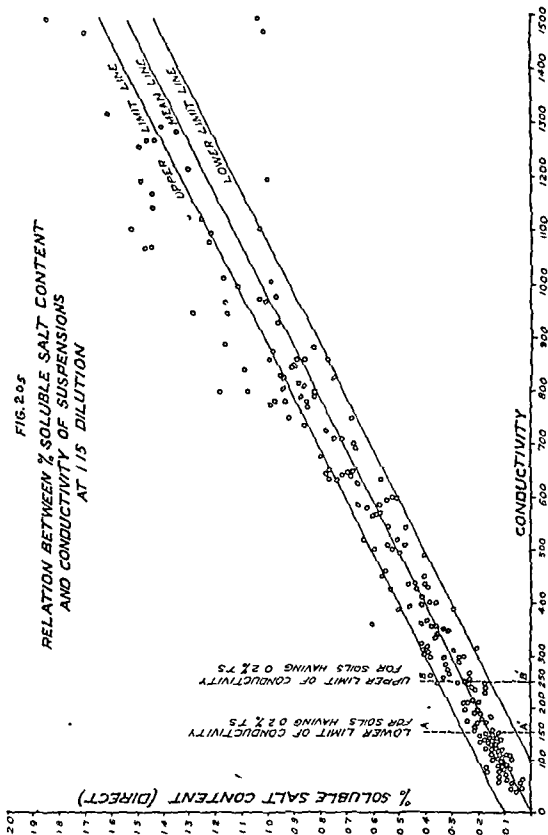
$$10^2 S = 0.26 C - 0.8 \quad (iii)$$

During the course of the work it was found that the conductivities of 1 : 15 soil suspensions divided by a thousand gave values equivalent to the salt content of soils directly determined, i.e.,

$$S = C/1000 \quad (iv)$$

FIG. 205

RELATION BETWEEN % SOLUBLE SALT CONTENT
AND CONDUCTIVITY OF SUSPENSIONS
AT 1:15 DILUTION



This observation means that for 1:15 soil suspensions the salt content of a soil can be determined from the conductivity value without the use of any complicated formula.

To test the relationship (iv) given above, the conductivities of a large number of soils at 1:15 dilution soil suspension were determined. The results of conductivity and total salt content determined directly are plotted in Figure 205. From the figure it will be seen that the points lie fairly well along the mean line. The two lines running parallel to the mean line and at a distance equivalent to 0.1 per cent salt content comprise almost all the points up to a salt content of 0.75 per cent. This indicates that up to a conductivity value of 750 the soluble salt content of soils is given by (iv) subject to a maximum error of 0.1 per cent (the actual error would be less). For soils having conductivity values greater than 750:

$$S = C/1000 + 0.1 \quad (v)$$

This formula is subject to a maximum error of 0.2 per cent.

2. *The physico-chemical effect of treating some of the Indian bentonites with sodium carbonate.*—Many varieties of bentonites manifest swelling in contact with water. If a mixture of sand and any one of these bentonites is wetted the pores in between the particles become filled on account of the swelling of the latter resulting in decreased permeability in water through the mixture. It was decided to examine the Indian bentonites to determine to what extent they could be used for reducing the permeability of sand.

Two of the more common varieties of Indian bentonites are those obtained from Kashmir and Jodhpur. The rates of permeability through standard sized briquettes made from mixtures of sand and 2 per cent of the various bentonites were measured with the help of the apparatus shown in Figure 206. For the sake of comparison Wyoming bentonite was also examined. The results of the percolation tests are given in the table below:—

Type of bentonite.	Rate of percolation in c.c. per minute under 10 feet head of water.		
Wyoming	0.06
Kashmir	46.0
Jodhpur	32.0

It is clear from the above table that whereas Wyoming bentonite rendered sand fairly impermeable to water the two Indian varieties produced little effect. The marked difference in the rates of percolation was shown to be due to the difference in the swelling property of the different bentonites. The amount of swelling is dependent upon the base in the exchange complex of the bentonite. It was shown, for instance, that whereas the Wyoming bentonite had a large percentage of sodium in its exchange complex, the Kashmir bentonite had calcium.

It was decided to examine the effect of interchange of bases in the exchange complex of the Indian bentonites. This was effected by treating the bentonites with sodium carbonate. In bentonites the swelling which is generally several times greater than the pore space is taken to be proportional to the amount of water absorbed. The latter was measured by a simple apparatus shown in Figure 207. It consisted of a glass sintered funnel of medium porosity (A), the lower limb of which was connected to a micro-burette (B). The portion below the sintered base (C) and up to the end of the graduated portion of the burette (E) was filled with distilled water. A weighed amount of the powdered bentonite sample previously dried at 110°C was spread quickly over the porous sintered base of the funnel and the latter lightly corked. The water absorbed during a particular interval was indicated by the position of the meniscus in the micro-burette. The progressive absorption of water by 1 gm. of bentonite samples treated with varying amount of sodium carbonate is plotted in Figures 208 and 209 against the time interval. To indicate the effect of sodium carbonate treatment the absorption of water by an equivalent amount of untreated samples of the two Indian bentonites and Wyoming bentonites is also plotted in those figures.

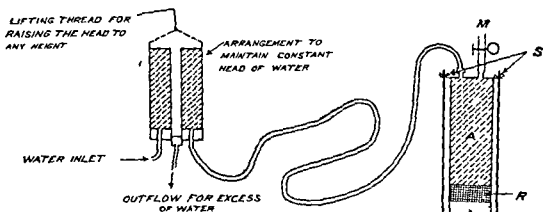
It is shown that :—

- (a) The untreated form of Jodhpur bentonite is capable of absorbing 3—4 times more water than the Kashmir variety.
- (b) There is a progressive swelling as indicated by the increased or relatively faster rate of water absorption up to a certain percentage of sodium carbonate for both the bentonites.
- (c) The effect of Na_2CO_3 treatment is more marked with the Kashmir variety. On treatment with 5.3 per cent Na_2CO_3 this variety of bentonite is capable of absorbing almost 15 times more water than the untreated samples. In the case of Jodhpur bentonite the maximum water absorption is about double of that absorbed by the untreated sample.

The following table gives the rates of percolation through briquettes made from sand and 2 per cent of the Na_2CO_3 treated samples of the Indian bentonites to produce their medium swelling :

		Kashmir.	Jodhpur.	Wyoming.
Sand and 2 per cent untreated bentonite	..	46	82	0.05
Sand and 2 per cent treated bentonite	..	1.7	20.7	..

FIG. 206



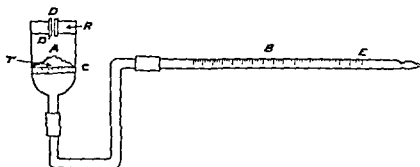
AA BRASS CYLINDER

R. RING CONTAINING MATERIAL FOR TEST TIGHTLY HELD BETWEEN A AND A'

G. FINE GAUZE SUPPORTING ORDINARY SAND

S SCREWNUTS TO HOLD DIFFERENT PARTS AND SECURE WATER TIGHTNESS OF APPARATUS

FIG. 207



APPARATUS FOR MEASURING THE ABSORPTION OF WATER BY BENTONITES

FIG 2.08
RATE OF WATER ABSORPTION BY 1 GRM OF OVEN DRIED
SAMPLES OF BENTONITES

UNTREATED KASHUR BENTONITE		
1	UNTREATED KASHUR BENTONITE	
2	WYOMING BENTONITE	
3	KASHUR BENTONITE TREATED WITH 2% H_2O_2 SOL	
4	" " " 3.5% "	
5	" " " 5.3% "	
6	" " " 7% "	

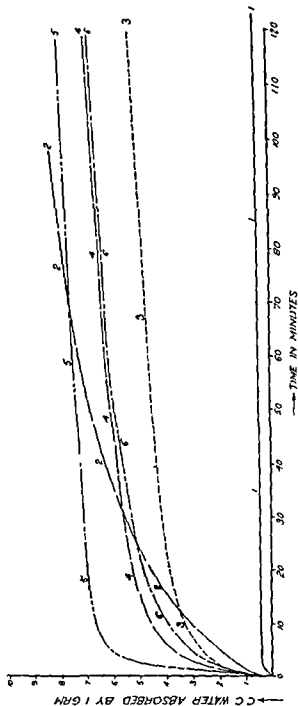
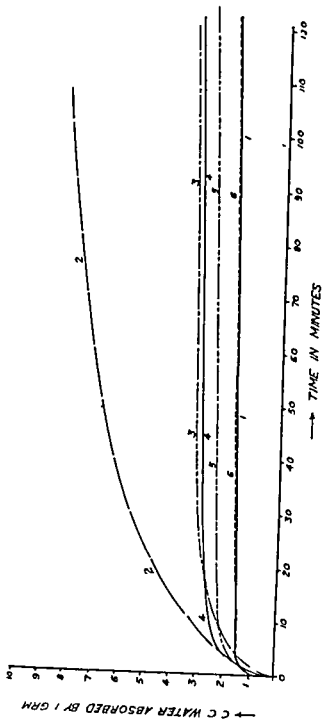


FIG 2.09
RATE OF WATER ABSORPTION BY 1 GRM OF OVEN DRIED
SAMPLES OF BENTONITES

1 UNTREATED JODHPUR BENTONITE	
1	UNTREATED JODHPUR BENTONITE
2	WYOMING BENTONITE
3	JODHPUR BENTONITE TREATED WITH 13.3% Na_2CO_3
4	" " " 2.65% " "
5	" " " 3.98% " "
6	" " " 5.3% " "



Statistical significance of the relationship.—The correlation between V (volume of soil absorbing 1 c.c. of water) and C (per cent clay derived statistically is given below and is represented by curve A :—

$$C = 2.149 + \frac{17.144}{V - 3.245} \quad (i)$$

Another correlation obtained by approximation which is presented by curve B is as follows :—

$$C = \frac{30}{V - 2.7} - 0.5 \quad (ii)$$

It will be seen that curve B affords a better fit to the points towards the two ends.

Limits of clay content corresponding to the volume of soil absorbing 1 c.c. of water.—A study of the distribution of the points plotted on the figure brings out four distinct zones.

Zone A : i.e., $V > 7, C < 7$.

Out of 21 cases where V exceeds 7 there are 20 which have clay content less than 7 per cent. Hence it may be accepted that V exceeds 7, C is very likely to be below 7 per cent.

Zone B, i.e., $5 < V < 7, C < 13$.

Out of 54 soils having V more than 5 only in two cases does the value of C exceed 13. Therefore, it may be taken as general that V is above 5, C is very likely to be below 13.

Zone C : i.e., $4 < V < 5, C < 25$.

Out of 86 soils having $V > 4$, 81 soils have their clay content less than 25. There are 9 soils having $V < 4$ and having clay content less than 25. Therefore, 81 cases out of 89 possess the right properties and in 9 cases out of 10 it can be expected that if V exceeds 4, C is less than 25 and *vice versa*.

Zone D : i.e., $V < 4$.

In this zone the curve gets very flat, i.e., even a small change in V will produce a large change in C and hence the accuracy of determination by this method is not very good. Out of 18 soils for which V is less than 4, in 15 cases C is more than 25 per cent. Although the indication afforded by this method that if V is less than 4, C is more than 25 per cent may be reasonably assumed to be correct it would be preferable that to know the exact clay content the direct determination is done.

The statistical examination, however, proves beyond doubt that the proposed method gives a reasonably good indication of the

FIG 210

RELATION BETWEEN C (CLAY %) AND
 V (VOLUME OF SOIL ABSORBING 1% C OF WATER)

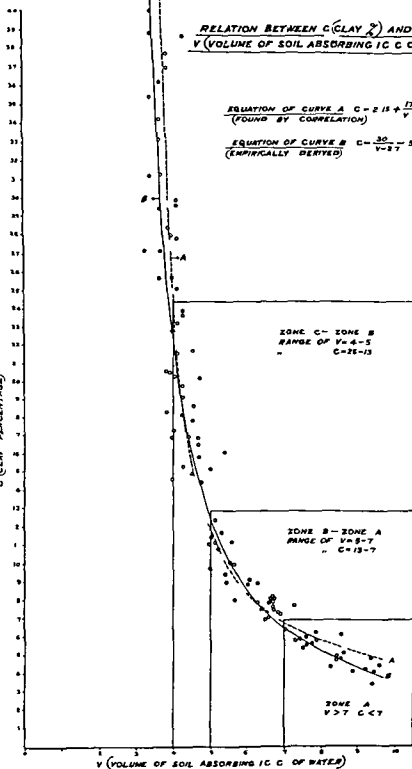
$$\text{EQUATION OF CURVE A } C = 2.15 + \frac{17.44}{V^{3.245}}$$

(FOUND BY CORRELATION)

$$\text{EQUATION OF CURVE B } C = \frac{30}{V-2.7} - 5$$

(EMPIRICALLY DERIVED)

C (CLAY PERCENTAGE)



clay content of such soils as have their clay contents between 3 per cent and 25 per cent. With soils having clay content below 3 per cent the blobs are not properly formed.

Effect of salts in soil on determination of clay—The presence of salts in soils in excess to .2—·3 per cent vitates the results. It is fairly easy to determine the soluble salt content of soils by conductometric methods in the field prior to the determination of clay. In cases where the salt content is higher than 0.2 per cent the soils can be given a preliminary leaching with water to remove the excessive salt content, dried, and then their clay content determined.

Along with the conductometric method of determining salt content of soils this method can be used in such field experiments as choice of kiln sites, destabilisation and earth road experiments.

The following papers have been accepted for publication:—

- (1) The conductometric method of determining the soluble salt content of soils for use in soil survey work.
- (2) A comparative study of the effect of certain soil factors on the yield of wheat in the Punjab.
- (3) A study of the carbon: nitrogen relationship of soils from the typical coniferous forests of the Himalayas.
- (4) The physico-chemical effects of treating some of the Indian bentonites with sodium carbonate.

**List of Research Publications Published by the Punjab Irrigation
Research Institute, Lahore (India)**

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- 2 A Statistical Examination of the Sensitivity of a Water table to Rain-fall and Irrigation, by Bernard Howell Wilsdon, with R Partha Sarathy (Re 1 or 1s 6d)
- 3 A Statistical Examination of the Discharge of the Indus at Sukkur and its Relation with Upstream Sites, by B H Wilsdon, with R Partha Sarathy, (Re 1 12 0 or 2s 4d)
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- 4 A Study of the Flow of Water under Works on Sand Foundations by Means of Models Part II by F McKenzie Taylor, M B F and Harbans Lal Uppal (Re 0 3 0 or 5d)
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- 9 Influence of an Upstream Sheet Pile on the Uplift Pressure on a Floor, by N K Bose, M Sc Ph D, Harbans Lal Uppal and E McKenzie Taylor, M B E (Re 1 4 0 or 1s 11d)
- 10 An Investigation of the Uplift Pressure on a Model of Bay IV, Khanki Weir and the Prototype, by A N Khosla E McKenzie Taylor, and Harbans Lal Uppal (Re 0-10 0 or 1s)

- 11 Pressures under a Model of Panjnad Weir and under the Prototype, by H. L. Uppal (Re 0 1 0 or 5d).
- 12 Design of Khanki Weir by VIII by I. P. Gurn and H. L. Uppal (Re 0 1 0 or 5d).
- 13 Uplift Pressure under a Depressed Floor, by Dr. N. K. Bose and H. L. Uppal (Re 0 7 0 or 8d).
- 14 The Effect of an End Sheet Pile on the Pressure Distribution under a Weir Floor and on the Exit Gradient by Dr. N. K. Bose and Harbans Lal Uppal (Re 0 1 1 0 or 1s 1d).
- 15 Punjab Practice in Silt Observations Dr. I. McKenzie Taylor, M.B.E. Director, Irrigation Research Institute, Lahore (India) (Re 0 6 0 or 7d).
- 16 The General theory of the Gradient of Pressure under a Structure on permeable foundations with applications to the evaluation of the Gradient at exit for some standard cases by Jai Krishan Malhotra and I. McKenzie Taylor (Re 0 1 0 or 1d).
- 17 Graphical Determination of Exit Gradient for some standard type of Structures, by Jai Krishan Malhotra and I. McKenzie Taylor (Re 0 1 0 or 7d).
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or 1s 10d)

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- 8 Soil Deterioration in the Canal Irrigation Areas of the Punjab, Part II Relation between Degree of Alkalization and Dispersion Coefficient in Deteriorated Soils, by A G Asghar, Amar Nath Puri and F McKenzie Taylor, (Re 040 or 5d)
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